A COMPARISON OF THE GROWTH OF *Eucalyptus viminalis* Labill. AND *E.melliodora* A.Cunn. IN CANBERRA IN RELATION TO URBAN PLANTATIONS

by

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DECLARATION

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of my knowledge, it contains no material previously published, or the result of any work by another person, except where due reference is made in the text.

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CONTENTS:

FIGURES:

LIST OF TABLES:

ABSTRACT

Eucalyptus viminalis Labill. has been widely used in Canberra for landscape plantings. In many of the plantings it has been unsuccessful and large numbers of trees have died. To determine reasons for the species' failure, an experimental plantation was set up and the growth of *E.viminalis* and the naturally occurring *Eucalyptus melliodora* A.Cunn. were compared. Differences in both growth form and rate were observed.

Of the climatic factors affecting seasonal growth, temperature had the strongest influence on *E.viminalis*. *E.melliodora* showed a possible photoperiodic response. While *E.viminalis* tolerated low winter temperatures successfully it was found to be more susceptible to high temperatures and associated water stress than *E.melliodora*. This was particularly important in regard to the early establishment of the trees. The establishment period was found to be fundamental for the long-term survival of the species.

E.viminalis attracted a wide variety of insect pests and was found to suffer much more insect damage than *E.melliodora*.

Assessment of local *E.viminalis* plantings of different seed provenances showed the mountain forest provenances to be the most successful.

CHAPTER ONE

INTRODUCTION

Trees of the genus *Eucalyptus* are widely used in landscape architecture. Many species grow well even though they appear to be out of their preferred habitat and are distant from centres of natural occurrence. It must be recognised, however, that as a result of the climatic changes in Australia over the past 10,000 years and the poor seed dispersal of most *Eucalyptus*, many species are probably not present in all sites to which they are adapted.

While the Australia-wide distribution of *Eucalyptus* is considered to have been principally effected by limited water and soil nutrients (Cremer, Cromer and Florence, 1978), the regional distribution of a species can rarely be attributed to one factor. Consequently, it is difficult to determine the optimum requirements for any one species and the selection of eucalypt species when introducing them into a new area can be complex. One possible criterion for selecting a species is its known ability to grow well in areas broadly comparable to the region into which it is being introduced. The factors which must be considered are climatic, edaphic and biotic. Information concerning the first two factors is often available from recorded data; however, the susceptibility of a species to, for example, insects, is much more difficult to gauge prior to introduction. As a result of this the success of a species can only be determined by field trials.

The introduction and assessment of *Eucalyptus* species for landscaping the city of Canberra was begun in 1912 by Thomas Weston. By 1920 over 50 species had already been planted for assessment.

Despite the apparent success of several of the species, Joseph Maiden (then Director of the Sydney Botanic Gardens) during a visit in 1919, reported that the use of *Eucalyptus* in horticulture was problematical, and under cultivation the form of the trees could not always be predicted. It was possibly because of this attitude that only a limited number of eucalypts were planted for landscaping purposes. The lack of native tree plantings was highlighted in 1944 by the Consultative Committee of Parks and Gardens who criticised Canberra's thoroughly un-Australian tree planting programme. The Committee advised that there were many eucalypts of the cold, dry tablelands that could be used (Murphy, 1979). Although eucalypts remained in the minority in landscape plantings until the mid-sixties, further species were assessed by Parks and Gardens and the Forestry and Timber Bureau (Cremer, 1969).

With the development of Woden Valley, Belconnen and Tuggeranong Creek in the 1960's and 1970's, the use of eucalypts (and other native plants) became widespread, and very few exotic trees were planted in Belconnen or Tuggeranong Creek. Accompanying the much greater use of eucalypts, problems with several of the species became evident, particularly in the unirrigated shelter belt plantings.

Shelter belt plantings have been important in areas which were naturally treeless or had been cleared for grazing. They are usually planted several years before building commences to allow time for the trees to grow and so reduce the exposure of new housing and recreational areas to strong winds and dust. They are also planted to break up the monotony of a newly established suburb.

Eucalyptus viminalis Labill. has been widely used in shelter belt plantings. It is often a tall and impressive tree species indigenous to several areas in the local region. It has, however, despite its local origin, grown poorly. Trees in plantations, after 5-7 years' growth, are frequently flat-topped, less than 3m tall, with no adult foliage and with large amounts of insect damage (see, Fig. 1.1). A good example was seen in Belconnen with large numbers having been planted near the present Lake Ginninderra. Several hundred of these trees died within about seven years of planting and more than two hectares have required a complete replanting.

To determine whether this failure of *E.viminalis* was peculiar to the Lake Ginninderra site, a number of different shelter belt plantations in both North and South Canberra have been examined. The trees assessed were from five to over twenty years old and the same poor performance has been found in all of the plantings,

FIG. 1.1 : *E. viminalis* in a shelter belt plantation after seven years' growth.

especially in plantings after 1970 (Richardson and Fryer, 1979).

In an attempt to determine the reasons as to why the species had been unsuccessful, information was sought from City Parks Administration field staff. However, the suggestions offered were vague and included poor planting techniques, excessive frost, drought or insect damage in a particular year, and so no common cause was identified. As *E.viminalis* occurs in both cold mountain areas and in hotter, drier woodland areas and occurred also in Canberra until recently it is difficult to understand why the species has grown so poorly. It is, perhaps, noteworthy that the performance was particularly poor in plantings made after 1970 when seedlings were grown from seed of the Lake George provenance.

Eucalyptus melliodora A.Cunn. is another species widely used in shelter belt plantations in Canberra. It is usually a successful species being adapted to and naturally occurring in the Canberra region as one of the two dominant tree species of the savanna woodland.

In order to identify the reason or reasons for the poor performance of *E.viminalis*, its growth was studied in comparison to that of the more successful *E.melliodora* with the hope that some important information pertinent to tree planting might emerge. Most of the growth data was obtained from an experimental plantation within which various treatments were imposed upon the trees to emphasise the effect of different environmental factors.

Other experiments were conducted to further examine the response of the tree species to those factors.

CHAPTER TWO

THE CANBERRA ENVIRONMENT AND THE EXPERIMENTAL PLANTATION

2.1 The Canberra Environment:

The Canberra region is characterised by dominant hills of low to moderate relief about 250m above the undulating plains which have an elevation of approximately 550m. Alluvial flats are restricted to the major watercourses (e.g. the Molonglo flood plain) and the fossil lake beds (e.g. Lyneham). Most urban development and associated tree plantations are on the undulating plains and on the lower slopes of the dominant hills.

2.1.1 Climate:

The Canberra climate is described as a continental type having hot summers and cold winters with considerable seasonal and diurnal temperature range. A summary of Canberra's climatological data is given in Table 2.1.

It should be noted that although Fairbairn is a known frost hollow it has been found that the data recorded there is representative for Canberra.

Canberra's annual rainfall is fairly uniformly distributed throughout the year with a slight winter low and spring peak. Although the uniform distribution of rain has been demonstrated over a number of years, the monthly distribution can often be erratic as shown by the 1980/81 record. Extremes of annual rainfall recorded have been from 250mm to 1050mm. The average monthly evaporation rate which is affected by temperature and day length is highest

TABLE 2.1

Climatological Data for Canberra*

	Jan.	Feb.	Mar.	Apr.	May	Month June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Temperature °C. Av. Max	27.5	26.7	24.3	19.6	14.9	12.1	11.1	12.7	15.8	19.0	22.3	26.1	
Av. Min	13.0	12.7	10.6	6.4	2.8	0.9	-0.4	0.7	2.8	5.8	8.3	11.1	
Rainfall (mm) Av.monthly	61	59	55	50	50	37	37	45	53	71	62	52	633
Evaporation (mm)	247	198	163	104	71	48	53	67	107	155	194	267	1672
Wind Av. speed (km/h)**	6.6	6.0	5.3	4.9	4.5	4.9	5.1	5.9	6.0	6.5	6.9	7.0	
Frost Days	0	0	0.3	4.9	14.5	18.1	21.2	18.9	13.5	6.2	2.0	0.3	99.9
Sunshine Daily (hrs.)	8.9	8.2	7.4	6.9	5.6	4.8	5.2	6.2	7.3	7.9	8.8	9.1	

Extremes: Temperature °C.

Max : 42.2
Min : -10.0

* From 1940-1979 - recorded at Fairbairn

** Recorded at Forestry and Timber Bureau, Yarralumla (Now CSIRO Division of Forest Research) in December and January. The high annual evaporation combined with the low annual rainfall makes Canberra a generally dry area for planting trees.

Frost damage to plants is a major problem associated with low temperatures and Canberra's average of 100 frost days a year is many more than most other Australian cities and towns.

The wind in Canberra is usually recorded coming from the North-West and gusting to over 120 km/h. It is most frequent in late spring and in summer and is partly responsible for the high evaporation rates recorded during those months.

When examining its extremes of climate it is possible to appreciate the restricting influence that the Canberra climate can have on tree growth and survival.

2.1.2 Soils:

A general pattern of soils in and around Canberra is shallow lithosols (less than 500mm) on the ridges and steep sided slopes; shallow podsolics with some red and yellow earths on hillslopes of low gradient, and; mainly duplex soils (podsolics, solodics and lithosols over a clay subsoil) and red and yellow earths on the rolling terrain of moderate slopes. The duplex soil is the most widespread in the Canberra region (Gunn *et al.*, 1969; Walker, 1978) and is the most important as regards tree plantations. The only large area of alluvial soil is in the Dairy Flat area where it occurs with minimal prairie soils and silaceous sands (Walker, 1978).

The duplex soils are noted for their almost impenetrable layer of clay which lies at less than 0.5m below the surface and as a result water rarely penetrates to a depth greater than 1m. This often increases the water run-off causing the soils to dry out rapidly, particularly on the slopes. In areas where there is a high silt content a hard crust tends to form on the surface thus reducing water permeability.

All of the soils (with the exception of the alluvial soils) are naturally infertile with low levels of phosphorus, nitrogen, molybdenum, boron and other trace elements. They are usually slightly acid to neutral and have a low salt (chloride) content.

2.1.3 Natural Vegetation

Even before stock were introduced into the area and it was cleared for grazing, much of the Canberra plains were treeless from about 525m to 600m (Pryor, 1968). The greater portion of the Canberra plains was probably *Themeda australis* grasslands. This grassland vegetation is thought to have occurred as a result of, most notably, cold air drainage and the resultant frost-hollows. Around the edges of the grassland areas a narrow band (about 100m wide) of either *Eucalyptus pauciflora* or *E.rubida* exists though there are now very few of these trees remaining in the Canberra area.

Above this band is an area of savanna woodland formed by *E.melliodora* and *E.blakelyi*. These two tree species are the most commonly occurring species in and around the urban area. In some parts of the city area the

E.blakelyi is replaced by *E.bridgesiana.* The trees of the woodland are widely spaced, leaving an open canopy and giving a parklike appearance. They usually do not exceed 20m and have short trunks and widely spreading crowns. The vegetation beneath the trees is a continuous cover of grasses, now mainly *Stipa* and *Danthonia* spp.

Above the savanna woodland to about 900m is the dry sclerophyll forest, which includes *E.macrorhyncha, E.rossii, E.mannifera* subsp. *maculosa* and *E.dives.* In Canberra this type of forest develops only in the low fertility soils. In contrast to the woodland savanna the trees grow closer together with smaller crowns and longer trunks in relation to the crown. They rarely exceed 20m in height and form a closed canopy. The vegetation beneath the trees is mainly small shrubs abundantly developed in a more or less continuous layer about 1m high.

Urban development mainly occupies the grassland and woodland areas, but also spreads into some of the forest areas where the slopes are not too steep.

2.2 The Experimental Plantation:

2.2.1 The *Eucalyptus* Species:

(i) *Eucalyptus viminalis* Labill.

Classification: Subgenus - Symphyomyrtus
Section - Maidenaria
Series - Viminales (Pryor and Johnson,1971)

Common Names: Ribbon Gum, Manna Gum, White Gum

Description: A tree with varied form depending on conditions, but often tall and shaft-like growing to 35m. The bark is rough and persistent on the lower half of the butt, or quite smooth throughout, white to yellowish-white and deciduous, often in long ribbons from the branches. Juvenile leaves are opposite, lanceolate and stem-clasping, becoming broader in areas of higher rainfall (Ladiges and Ashton, 1974). Adult leaves are alternate, petiolate, lanceolate, long and narrow (110-180x15-20mm). Flower buds usually occur in threes on a short peduncle with a conical operculum. Flowers are white appearing mostly from late spring to autumn. Fruits are spherical to conical with protruding valves (Blakely,1965;Holliday and Watton,1980).

Habitat: *Eucalyptus viminalus* occurs in a great variety of topographical localities ranging from mountains and tablelands to coastal flats. It grows on a wide range of soils, from impoverished sandy podsols to rich alluvia, and from well-drained skeletal soils of volcanic scoria to seasonally waterlogged soils of old peneplains. The species is found from sea-level to over 1300m in areas with mild summers and cool to cold winters and with annual rainfall of 625-1150mm (Hall, Johnston and Chippendale, 1975).

Occurrence:

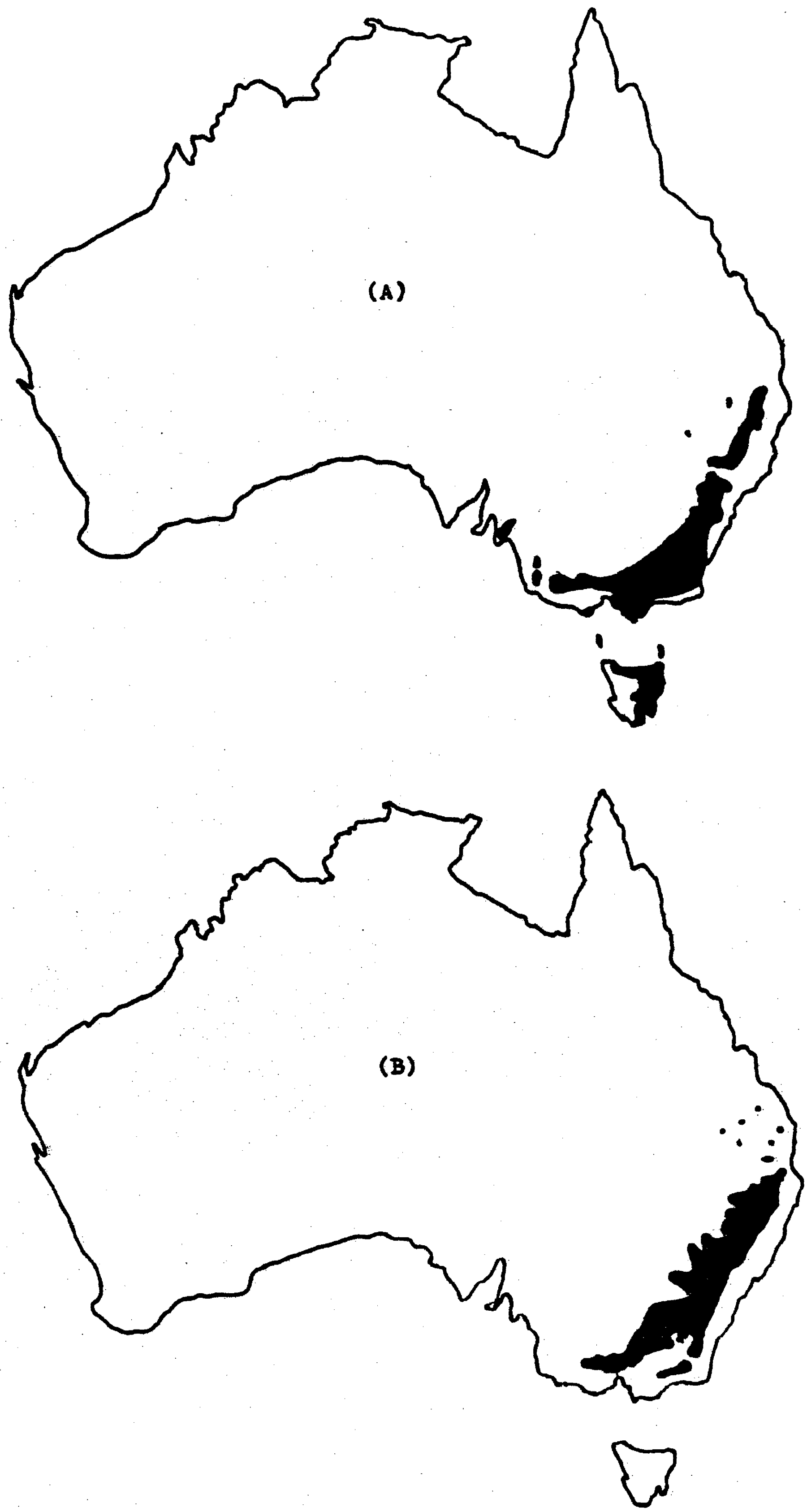
Australia: With its range of available habitats the species has a wide distribution in south-eastern Australia (see, Fig. 2.1). It is common in the north-western and eastern regions of Tasmania and in eastern and central western Victoria, occurring also on the Flinders and King Islands in the Bass Strait. In New South Wales it is mainly scattered throughout the tablelands with occasional stands at

FIG. 2.1: The distribution in Australia of,

(A) *Eucalyptus viminalis* Labill.

(B) *Eucalyptus melliodora* A. Cunn.

(after Hall *et al.*, 1975, and
Chippendale and Wolf, 1981)


(A)
(B)

higher altitudes, into southern Queensland. The main occurrence in South Australia is in the Lofty Ranges, near Adelaide.

A.C.T. and the Surrounding Districts: Occurrence of the species in the A.C.T. (see, Fig.2.2) is mainly confined to the wetter mountain areas, although it is found in the drier Murrumbidgee valley along the river, such as at the Murrumbidgee-Cotter River junction and on the Murrumbidgee River floodplain near Tharwa (see, Fig. 2.3). The species did occur along the Molonglo River in the Canberra City area in the old Royal Canberra Golf Course, but was removed when Lake Burley Griffin was filled (Pryor, 1968). Although the species usually occurs in the lower more sheltered mountain gullies it has been observed as a much smaller form near the summit of Mt. Coree (alt. 1420m) (Paton, pers. comm.). There are several other occurrences of *E.viminalis* in close vicinity to the A.C.T. border, the best known being near Lake George on its western shore (see, Fig. 2.4). These are apparently a woodland form and are found at the top of the Lake George scarp and west of it towards the A.C.T. border, as well as actually along the lake shore. The same woodland form is also found east of Lake George near Tarago. South-east of Canberra there are two distinct occurrences. The first between Burra and Queanbeyan on a tributary of the Jerrabomberra Creek (see, Fig. 2.4) and the second is in the Gourock Highlands from near Bungendore through Captains Flat and south towards the Victorian border. Other occurrences are found east of

FIG. 2.2: The distribution of *Eucalyptus viminalis* and *Eucalyptus melliodora* in the Australian Capital Territory.

(after Pryor, 1954)

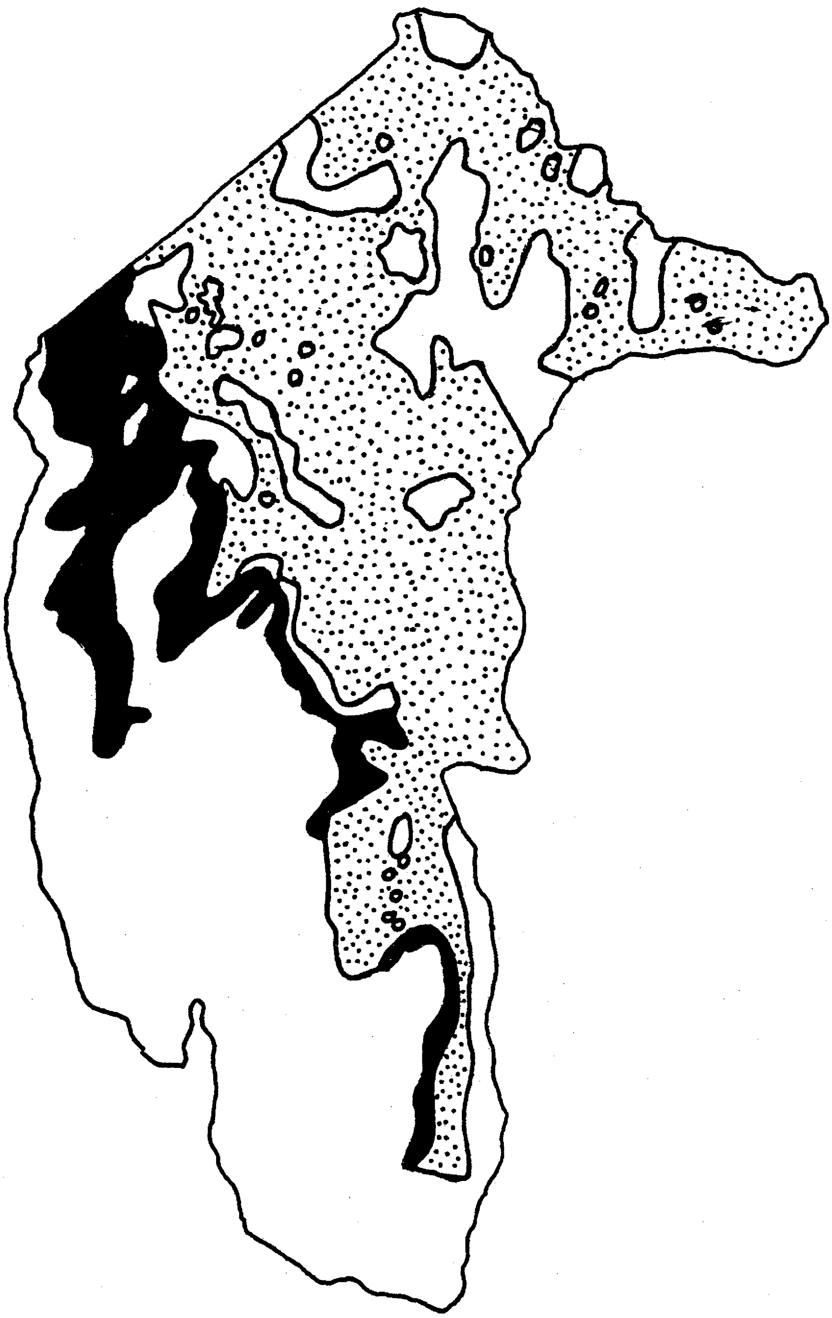


FIG. 2.3: *E.viminalis* occurring in the A.C.T. at

(A) Condor Creek in the Brindabella Ranges west of Canberra, and along the Murrumbidgee River at

(B) the Junction with the Cotter River, and

(C) near Tharwa.

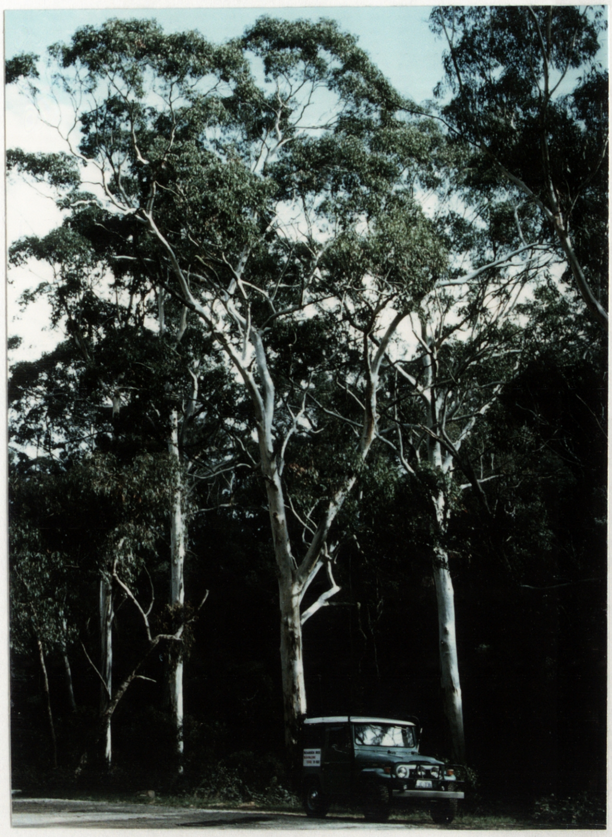
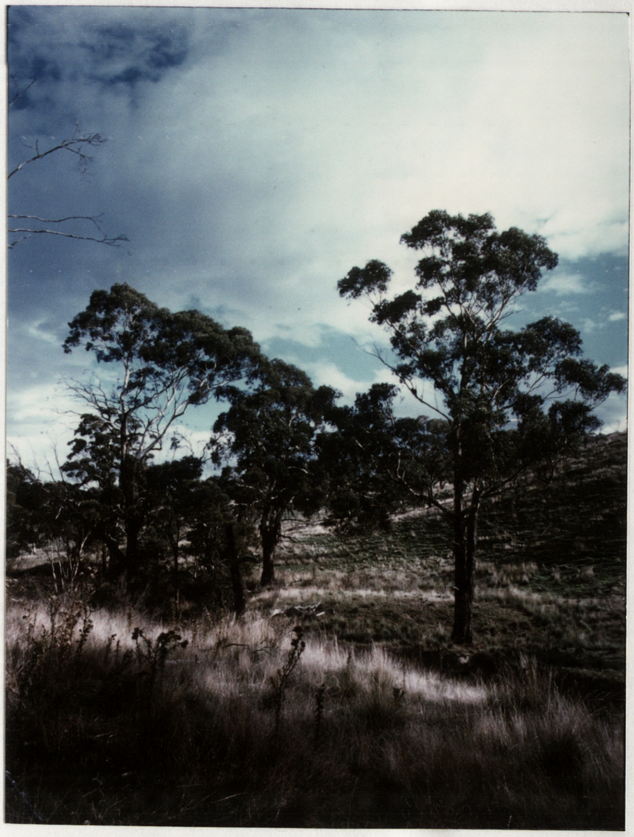


FIG. 2.4: *E.viminalis* occurring at Lake George,

(A) along the Lake-shore,

(B) on the scarp, and also occurring

(C) on a tributary of the Jerrabombera Creek near Burra, N.S.W.



Bungendore along the Kings Highway. Two other sites examined were the virtually pure stand of *E.viminalis* near Monga, east of Braidwood and a site at Cowra Creek, east of Bredbo.

E.viminalis Alliances and Associations in the A.C.T. Region

In the A.C.T. and surrounding districts the species is part of four eucalypt alliances and within these is part of several associations. The four alliances are: *E.melliodora-E.blakelyi*; *E.pauciflora-E.stellulata* ; *E.delegatensis-E.dalrympleana*, and *E.fastigata-E.viminalis*. The latter, being the most common *E.viminalis* alliance in the A.C.T., occurs in the mountains to the west and south of Canberra at elevations of 800-1100m (Pryor, 1954). The main associations in this alliance are the *E.fastigata-E.viminalis* and the *E.viminalis-E.robertsonii*. The sequence of the former association to the latter is seen with decreasingly favourable conditions of moisture and temperature. The alliance develops best under mild, humid conditions with the rainfall in the mountains being between 860-1100mm per annum, with a summer maximum (Pryor, 1954; Costin, 1954). The much more frequent occurrence of the alliance at the northern end of A.C.T.'s western ranges indicates that it needs higher temperatures than those experienced to the south-west where it is not found. This same alliance is found to the east of Canberra in the Gourock Highlands. In the drier areas of this eastern occurrence the *E.viminalis-E.dives* association is also present. Costin (1954) notes that the alliance occurs in different soils independent of their parent rock type, but does not occur in soils poorly drained or poorly aerated, which would restrict them from valley floors in high rainfall areas.

Higher in the mountain region *E.viminalis* also occurs in the *E.delegatensis-E.dalrympleana* alliance. This occurrence is in the *E.delegatensis-E.viminalis* association, and is limited to the sheltered gullies. The alliance occurs from 1100-1500m where the annual rainfall is 980-1225mm. The soil requirements are the same for the *E.fastigata-E.viminalis* alliance.

Another less common occurrence in the A.C.T. is in the *E.melliodora-E.blakelyi* alliance. The species is in the *E.bridgesiana-E.viminalis* association as is seen near the Murrumbidgee-Cotter River junction, though it has been greatly disturbed by recreation developments in the area. The trees growing at Tharwa were also probably part of the same alliance but clearing for grazing has removed the other trees growing in association with them. The *E.bridgesiana-E.viminalis* association is more easily seen on the western side of Lake George. In this area and in the areas east of Bungendore along the Kings Highway, the *E. bridgesiana-E.viminalis* association (and the *E.bridgesiana-E.rubida* association often found close-by) replaces the *E.bridgesiana* association under hilly to rather undulating, but cooler conditions transitional to those of the *E.pauciflora-E.stellulata* alliance. The *E.bridgesiana-E.viminalis* association found between Burra and Queanbeyan is quite different to that occurring near

Bungendore. This second occurrence of the association is not transitional to a colder area but rather to a drier area occupied by the dry sclerophyll *E.goniocalyx-E.rossii* association. The *E.viminalis* and the *E.bridgesiana* was found growing in the shallow valley of a creek in the dry sclerophyll forest. A description of the climatic and soil requirements of the *E.melliodora-E.blakelyi* alliance is given in the description of *E.melliodora*.

The last alliance in which *E.viminalis* occurs is the *E.pauciflora-E.stellulata* alliance. Like the *E.melliodora-E.blakelyi* alliance this is considered to be a woodland type. The chief difference between the two woodland alliances is the lower temperatures and, in most areas, the consequently shorter growing season under which the *E.pauciflora-E.stellulata* alliance develops. The *E.pauciflora-E.viminalis* association observed at Cowra Creek, east of Bredbo cannot really be considered as a woodland association. The two species are growing on the sandbanks in the bed of Cowra Creek which runs through shale. The surrounding slopes are vegetated by various associations of the dry sclerophyll *E.macrorhyncha-E.rossii* alliance. With the same dry sclerophyll forest occurring on Black Mountain in Canberra and the remainder of a *E. pauciflora* stand north of Acacia Inlet (Lake Burley Griffin), the original stand of *E.viminalis* on the sandbanks of the Molonglo River may have been a similar association as that at Cowra Creek. The *E.pauciflora-E.stellulata* alliance also occurs on different soils independent of the parent rock (Costin, 1954).

The local distribution of *E.viminalis* and the alliances and associations of which it is a part suggests that it is a transitional species. The transition is principally between moist and cold and dry and hot. The fact that the species is able to occupy these transitional areas could explain its extensive occurrence in Australia and also its survival in areas where other forest species have died out due to reduced rainfall (e.g. Lake George). However, the information presented does not suggest that *E.viminalis* is suitably adapted to survive in drier woodland areas, such as around Canberra, unless on permanent water courses (e.g. Molonglo River).

Seed Provenance of Experimental Plantation Seedlings:

The seed was collected by City Parks Administration from the trees next to the Federal Highway on the western shore of Lake George. The trees are part of the *E.bridgesiana-E.viminalis* association mentioned above. It is the seed provenance presently used for propagation.

(ii) *Eucalyptus melliodora* A. Cunn.

Classification: Subgenus - Symphomyrtus
Section - Adnataria
Series - Melliodorae (Pryor and Johnson, 1971)

Common Names : Yellow Box, Honey Box (Qld.), and Yellow Ironbark (Qld.).

Description: A medium sized to very tall, graceful tree (see, Fig.2.5). The bark is scaly flaky to subfibrous

FIG. 2.5: *E.melliodora* growing in savanna woodland in Canberra. The tree to the left of the *E.melliodora* is *E.blakelyi*, the species most commonly associated with the former in the Canberra region.

and persistent on the trunk, smooth and greyish on branches. Amount of trunk covered variable. Juvenile leaves are alternate, petiolate, oblong to elliptical and subglaucous. Mature leaves are alternate, petiolate and narrow to broad lanceolate. They are sometimes also subglaucous. Flower buds occur in threes to sevens and are auxillary or in terminal panicles. Flowers are cream (rarely pink), profuse, appearing in spring, summer and autumn. The operculum is conical, the fruit hemispherical to sub-spherical and the valves are enclosed (Blakely, 1965; Holliday and Watton, 1980).

Habitat: It is a species of the savanna woodland and open forest. It occurs mainly on gentle slopes and foothills, but is restricted to the flats near water-courses in the drier parts of its range. The best development of the species is on light to somewhat heavy alluvial soils, loams and sandy loams. The altitude range is mainly 150-600mm but extends to 1200m on the northern tablelands of N.S.W. It occurs in areas where the summers are warm to hot and the winters are cool to cold with 5-100 frosts a year. The annual rainfall is 375-875mm with the wet season varying from winter in Victoria to summer in northern N.S.W. and Queensland (Hall *et al.*, 1975).

Occurrence:

Australia: Although it does not occupy the range of habitats of *E.viminalis* the species is still widely distributed in Victoria and N.S.W., especially on the inland side of the Great Dividing Range (see, Fig.2.1). There is also a small extension into Queensland.

A.C.T. and the Surrounding Districts: *Eucalyptus melliodora* is, with *E.blakelyi*, the most common eucalypt species occurring in the Canberra city area. Its occurrence in the A.C.T. is shown in Fig.2.2. Outside of the A.C.T. the species is widespread on the southern tablelands.

E.melliodora Alliances and Associations in the A.C.T. Region :

Unlike *E.viminalis*, *E.melliodora* is part of only two alliances in the A.C.T. and surrounding districts. These alliances are: the *E.melliodora-E.blakelyi* alliance, and the *E.albens-Callitris glauca* alliance.

The first of these is by far the most important, especially in the A.C.T., where it occupies the Canberra plains and the Tidbinbilla Valley. It extends south to Naas and about 25km up the Naas Creek, and north to the Territory boundary. It is usually growing in areas below 750m with a rainfall of about 600mm per annum, where severe summer droughts can occur and where mean monthly temperatures are among the highest experienced in the A.C.T. and Monaro area (Pryor, 1954). The alliance occurs on soils derived from most rock types except basalt and is excluded from frost-hollows and from soils which are water-logged.

Within the alliance, *E.melliodora* is part of two associations. These are the *E.melliodora-E.blakelyi* association and the *E.melliodora-E.bridgesiana* association.

Both of these associations occur in the Canberra city area and the latter is also found between the former association and the *E.bridgesiana-E.viminalis* association near Lake George.

The second alliance, namely the *E.albens-Callitris glauca* alliance is not found in the A.C.T. but the *E.albens-E.melliodora* association occurs near Murrumbateman, north-west of the A.C.T. boundary. It is found on less sloping areas, transitional to the *E.melliodora-E.blakelyi* alliance. The climatic requirements of the association are very similar to those of the *E.melliodora-E.blakelyi* association, though the normal monthly temperatures are probably slightly higher.

As is illustrated by the distribution of *E.melliodora* and by the plant communities of which it is a part, the species is obviously adapted to the large areas of savanna woodland in the A.C.T., with their moderately low rainfall and high summer temperatures.

Seed Provenance of the Experimental Plantation Seedlings:

The seed was collected by the City Parks Administration from a tree near the suburb of Charnwood, Canberra, A.C.T. The tree was part of the *E.melliodora-E.blakelyi* association.

2.2.2 Location of the Experimental Plantation:

The experimental area was within the City Parks Administration Research Plot situated in South Canberra to the north of Curtin on the Cotter Road. This area has also been known as the "Woolshed Plantation".

The plantation was planted on a strip of land 60 metres long and 35 metres wide. As a consequence of its WSW-ESE alignment, the plantation received the full effect of the sun and the predominant north-westerly and westerly winds. The only shelter the plantation received was from a large windbreak of *Cupressus* trees (about 8m tall) six metres to the south of the plantation, protecting it from the occasional southerly, south-easterly and south-westerly winds.

2.2.3 Soil:

The Cotter Plots area is part of the "Florey" soil-landscape association which occurs on gently sloping terrain (Walker, 1978). In this association there is a higher proportion of moderately to poorly drained soils than that occurring on the rolling hillslope terrain (the "Wanniassa" soil-landscape association). An analysis of the soil sampled over the plot indicated it to be a clay loam with a pH of 6.5.

2.2.4 Site Preparation:

Before the trees were planted the plot was ripped to a depth of 400mm at 2m intervals, and then rotary hoed to a depth of about 250mm. A 2m wide strip of land between the *Cupressus* trees and the proposed plantation was ripped to a depth of about 400mm to remove any large roots growing into the plot.

2.2.5 Plantation Design and Planting:

The plantation was designed to imitate, as closely as possible, the plantations used as shelter-belts around

Canberra. The design normally consists of a number of tree species, commonly eucalypts, in parallel lines. While a shelter belt plantation usually consists of more than two species, the use of two species allows for a better assessment of the conditions prevailing in a plantation.

After site preparation the area was divided into three main plots, 7m apart, each of which was divided into four or two sub-plots, 3.5m apart. A summary of the treatment randomly allotted to each sub-plot is given in Table 2.2.

TABLE 2.2

Treatments used in Experimental Plantation

Plot 1	Treatment All sprayed for insects	No. of *E.viminalis*	No.of *E.melliodora*
Sub-plot 1	Irrigated	12	12
2	Not irrigated	"	"
3	Frost protected (irrigated)	"	"
4	Wind protected "	"	"
Plot 2	All sprayed for insects		
Sub-plot 1	Irrigated, not mulched	12	12
2	Not irrigated, mulched	"	"
3	Not irrigated, not mulched	"	"
4	Irrigated, mulched	"	"
Plot 3	Not sprayed for insects		
Sub-plot 1	Irrigated	6	6
2	Not irrigated	"	"
	Total	108	108

The seed for the trees was sown in September, 1979 and the trees were planted on the 4th January, 1980. For each sub-plot the tree species were planted alternately (as in many shelter plantations) in eight rows of three at intervals of 2.5m. After planting, each tree was watered in with about 10 litres of water filling the soil basins formed around each tree. Each tree was fertilized two weeks later with 70gm of Multigro (N:P:K ,10:4:6) fertilizer spread evenly around the basin and the trees were again watered.

2.2.6 <u>Preliminary Establishment</u>:

In accordance with normal shelterbelt plantation practice, the trees in all three of the plots were "established" for the first three months. Establishment involves irrigation and insect control for three months after the trees have been planted.

The insect control involved only one spraying in March, 1980. To simplify the watering during the establishment period an overhead irrigation system was installed. This was arranged so that the entire area received an equal distribution of water. The plot was irrigated once a week for a period of 2 hours, with about 30mm of water at each watering. Watering continued until April 3rd, 1980 at which time all of the trees were watered by hand to ensure that the soil moisture was at field capacity before commencing the experiment.

By the end of the establishment period, it was found that some of the trees were smaller than average. As these trees were nearest to the *Cupressus* planting the dividing area was again ripped, this time to 600mm.

Several large *Cupressus* roots were found to be still present. The area was then ripped on a twelve monthly basis and the growth of the trees was not seen to be further restricted.

2.2.7 Commencement of Treatments:

After the initial measurement of tree height and stem diameter the treatments were commenced. Irrigation, wind protection and mulching were all started from the 4 April, 1980 and frost protection was used when necessary.

(i) Irrigation:

Irrigation was originally carried out by hand using a hose and filling the surrounding basin to overflowing with each tree receiving about 10 litres of water. The necessity for watering was determined using an electric tensiometer. On average the water content of the soil did not fall below about 15% with the water content of the soil at field capacity being 23%. The hand watering was continued until December, 1980 when a trickle irrigation system was installed. The trees were irrigated for 2½ hours for each watering period with each tree receiving about 10 litres of water. The only water received by those trees not irrigated was from rain.

(ii) Wind Protection:

The sub-plot used was selected as being the most suitable to observe the effects of wind protection on the tree growth, as it was the most south-easterly of the sub-plots. This meant that it would be the most protected from predominant north-westerly and westerly winds.Until the other trees had reached a height that would afford some wind protection, a suitable wind-break had to be erected. The wind-break was 1m high and was made of 50% Sarlon shade-cloth. The height of the wind-break was selected to ensure that it would not interfere with the sunlight during most of the day. The effectiveness of the wind-break was checked with measurements of the wind speed taken outside and 3m inside the wind-break. Simultaneous measurements showed the reduction of a 24km/h wind to about 8km/h or a reduction to about 33% of "free" wind speed. The wind-break was aligned to reduce northerly, north-westerly and westerly winds. The plantation of *Cupressus* trees made an effective break for any southerly winds. The 1m high wind-break was only effective on the *E.viminalis* in the first autumn, winter and in the beginning of the first spring. The height of the wind-break could not be increased as it would have shaded the smaller *E.melliodora*. However, by this time the crowns of the trees in the other plots had also increased in size and were providing the partial protection usually afforded to trees on the leeward side of a plantation.

(iii) <u>Frost Protection</u>:

To examine the effect of frost protection on the growth of the trees, large hessian sacks were used to cover the *E.melliodora* and hessian hung on wooden stakes was used for the *E.viminalis* (see, Fig.2.6). The covers were used on the nights when frost was anticipated. They were put on the trees at about 4.15pm and removed at about 7.45am. As this was mainly in mid-winter the effect of shading was minimal. Unfortunately, the covers could only be used for the first

Fig. 2.6: Hessian covers used to provide frost protection for the *E.viminalis* and *E.melliodora* during the winter of 1981.

winter, as the *E.viminalis* were too tall to make putting frost covers on them practicable in the second winter. However, the trees were closely examined in the second winter after each frost for damage.

(iv) Mulching:

The mulch used was shredded pine wood-wastes and was applied to a depth of about 75mm around each tree and to a distance of about 300mm from the trunk.

2.2.8 Fertilising:

A further 70gms of Multigro was applied to each tree at the beginning of spring and autumn to reduce the chance of the tree growth being affected by a lack of nutrients.

2.2.9 Pest Control:

Insect control: The insecticide primarily used was Rogor 40 with or without white oil. This insecticide is a systemic poison and so is effective on both leaf-chewing and sap-sucking insects. White oil was used if scale insects were found to be present. The timing of the spraying was mainly based on observation. That is, when a specific insect population appeared to be becoming a problem the trees were sprayed accordingly. The spraying was very successful on resident populations such as scale, lerps or insect larvae. It was not possible to guarantee an effective control of migratory insects such as Christmas Beetles (*Anaplognanthus* sp.); however, they did not appear to be as destructive because they were present during periods of reduced growth.

Vermin control: A problem met with early in the project was rabbit and hare damage to young trees. Although nearly 50% of the trees lost at least one branch, only one tree was chewed to almost ground level. The rabbits and hares appeared to have a preference for the *E.melliodora* but most of the trees were small enough to be protected with wire cages. Complete control was not achieved until City Parks Administration Rangers reduced the rabbit and hare populations by shooting. One tree also suffered the ravages of cockatoos, but the damage was only minor and there were no further attacks by birds. The only other damage caused by birds was when large birds, usually magpies, attempted to land in the crowns of the young *E.viminalis*.

Weed control: This was achieved by hand weeding the basins. The greatest amount of weed growth was in the basins of those trees irrigated and unmulched. The weed problem around the trees slowly became less as the density of the foliage in the crown and the leaf litter on the ground increased.

The grass growing between the trees was mown. This was carried out not only to keep the plots tidy as in urban plantations but also to reduce the amount of weed seed going into the basins.

2.2.10 An Extension to the Plantation:

By the end of the first twelve months of measurements it was decided that a further treatment needed to be introduced. This involved growing trees without an "establishment period". Six trees of each species, *E.viminalis* and *E.melliodora*, were planted at 2.5m intervals, in the same pattern as those planted in the other plots. The trees were also about three months old and of the same provenances as those in the other plots. The trees were planted out on the 25th February, 1981. These were not planted out in mid-summer because of the intended treatment.

Once planted, each tree was given 10 litres of water. Two weeks later 70gms of Multigro fertiliser was placed around the base of each tree and was watered in. This watering was repeated three days later to ensure that the fertiliser was not concentrated in the top 20mm of the soil. After this third watering the trees were not irrigated or sprayed for insects until the conclusion of the experiment in May, 1982. The sub-plot most similar to Plot 4 was that sub-plot not irrigated and not sprayed. The difference was that it received the three month establishment period during which it was irrigated and sprayed. The first measurements of height and stem diameter on Plot 4 were taken on the 29th May, 1981 which allowed a preliminary growth period of three months as in the other plots. Plot 4 was fertilised in the same way and at the same time as the other plots.

2.2.11 Meteorological Measurements in the Experimental Plantation:

Prior to commencing the treatments in April, 1980, various meteorological instruments were set up between Plots 1 and 2. Temperature, rainfall, humidity and wind-speed were measured. The temperature and humidity were measured using a thermohygrograph which was housed in a

Stevensen screen 1.2 metres above the ground.

Total wind was measured using a cup anemometer mounted at 2m. The rainfall was measured at ground level using a standard 100mm raingauge. Rainfall was measured daily.

The recordings of the above climatic variables are presented in Figs. 4.18 to 4.22 and Table 4.4.

CHAPTER THREE

THE GROWTH OF *E.viminalis* and *E.melliodora*.

OBSERVATIONS AND RESULTS

3.1 *Eucalyptus* Growth with Reference to *E.viminalis* and *E.melliodora*:

Bud, leaf and shoot development of the eucalypt is, as far as it is known, indeterminate in that it tends to be continuous and to occur whenever the conditions are favourable. There appears to be no requirement for overwintering (Jacobs, 1955;Cremer, 1972;1975). Whole systems of shoots may originate from a single bud in one season and annual shoots are morphologically not definable.

The development of new shoots and the resultant height growth in eucalypts, occurs in four ways. The first of these explains why eucalypts are capable of continued growth, providing the conditions are favourable.

In *E.viminalis*, early in each growing season, a growing tip ("naked bud", Jacob, 1936), may be observed in the axil of each new leaf, unless it has been damaged by insects. These buds are capable of rapid extension in length from the time the last leaf unfolds. In the course of growth they produce leaves at about 40mm intervals. In the axil of each of these new leaves there is another naked bud which can continue the growth process. The positions of these growth tips on the juvenile *E.viminalis* are shown in Fig. 3.1. As can be seen from the illustration each bud consists of the growing tip concealed by the next two leaves.

The buds on *E.melliodora* are not as obviously covered by the next leaves as on *E.viminalis*. They are, in fact, very exposed. The problem of exposure is highlighted when any buds left exposed to frosts become desiccated. During periods of extreme temperatures no new buds are visible (see, Fig.3.3). When growing conditions improve, new buds appear (see, Fig.3.4). These probably arise from the meristematic region at the base of each naked bud which can be organised into a new naked bud. Once the growth has begun the growth pattern is the same as with other eucalypts, with a new bud appearing in the axil of each new leaf. The rate at which new leaves are produced appears to be much faster in *E.melliodora* than in *E.viminalis*, (see, Fig.3.2). In the top 100mm of the *E.viminalis* shoot in Fig. 3.1 there have been 15 possible growing tips produced, while on the *E.melliodora* there are 30.

Although *E.melliodora* produces leaves at as much as twice the rate of *E.viminalis*, its height does not increase at the same rate. The internodal extension of *E.viminalis* is by far the more rapid. This is indicated by the height measurements (Table 3.1) of the two species. The faster growth rate is also aided by the fact that *E.viminalis* is more likely to maintain one dominant leader.

The second method eucalypts have to produce new shoots and branches is that mentioned in relation to *E.melliodora*. It involves the stimulation of the

FIG. 3.1: Distribution of naked buds on a juvenile *E.viminalis* branchlet.

FIG. 3.2: Distribution of naked buds on a juvenile *E.melliodora* branchlet.

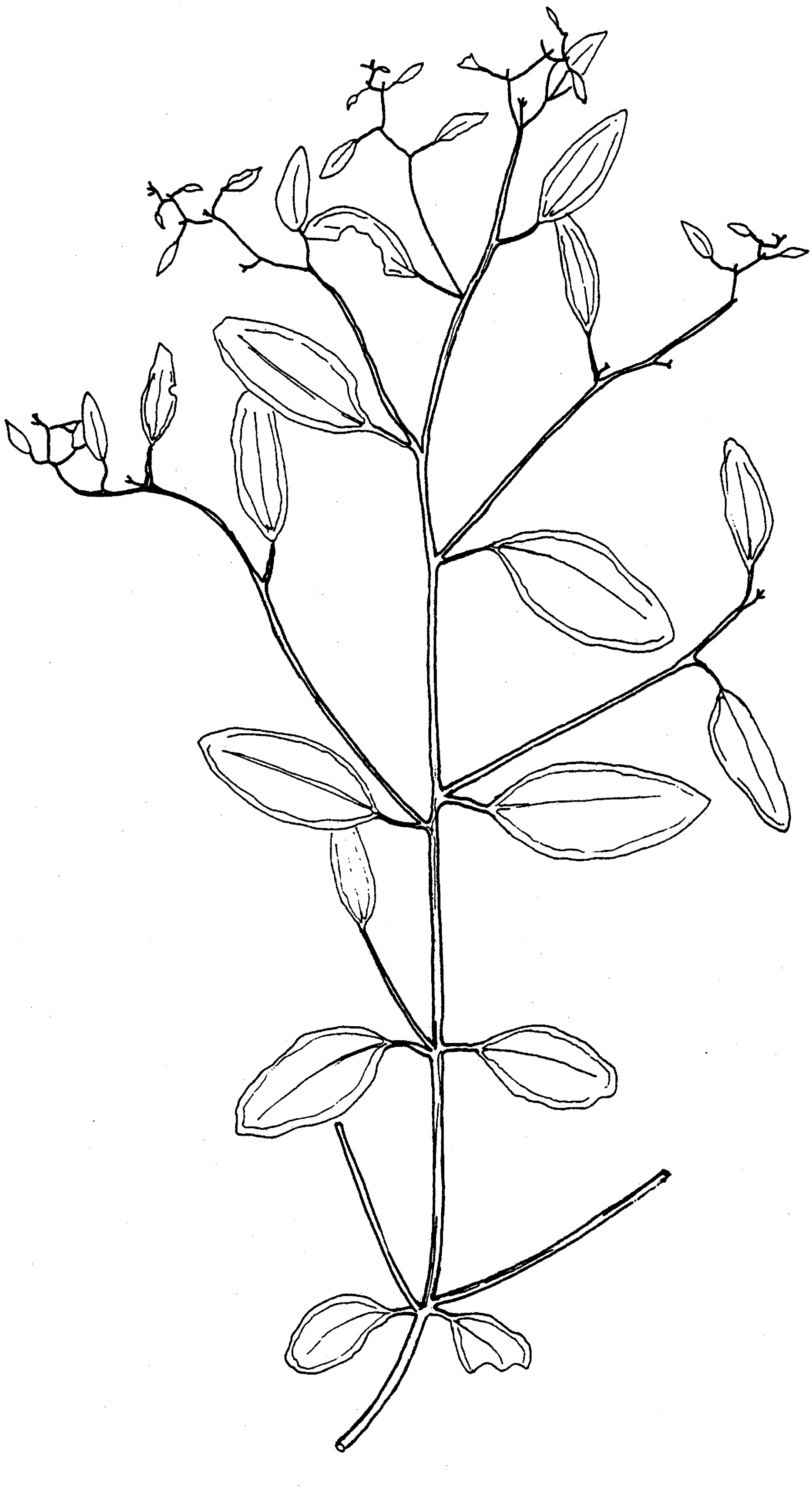


FIG. 3.3: Dormant *E.melliodora* with no naked buds in mid-winter.

FIG. 3.4: Early shoot development on *E.melliodora* in spring.

meristematic region forming an accessory bud at the base of each naked bud. Jacobs (1936) refers to these as "concealed buds". These accessory buds are regarded as one of the reasons for the survival of many of the species within the genus *Eucalyptus*.

The remaining two methods of producing new shoots are initiated by more extensive damage to the tree than minor insect damage. The type of damage that usually stimulates these methods is that occurring in a fire, when all the young growing tips of the tree are destroyed.

The first involves the use of 'proventitious buds'. Irrespective of the fate of the naked buds and leaves, the leaf-producing potential of the meristematic tissue in any leaf axil is not lost to a eucalypt as long as the branch which produced the leaf axil is alive on the tree. If the branch remains alive, a small shaft of tissue with meristematic properties grows radially outwards from the leaf axil as the stem increases in size, with its terminus in the live bark or at the wood surface. Each shaft is capable of producing leafy shoots but is kept in check by the natural inhibitory effects of the crown above. If the crown is destroyed this inhibition is removed and a bunch of several shoots may grow from one or more of these meristematic shafts on the tree trunk and branches (Jacob, 1955). The use of this method was seen in *E.melliodora* on a plant where the entire growing tip had been removed by a hare, leaving only the main stem and three leaves. This method again increases the eucalypts' chance of survival, especially when one considers the reserve at least one meristematic shaft for each leaf formed on the trunk represents.

The last method of producing new shoots involves lignotubers and root swellings. In eucalypt species which have lignotubers, small swellings form in the axil of the cotyledons or the first pair or two pairs of leaves on the seedling. As the seedling ages the swellings in the individual leaf axils fuse and increase in size and form a bulbous mass, first termed lignotubers by Kerr (1925). The lignotuber then tends to move down the stem and thus bury itself. The lignotubers appear to be modified stem structures arising from the accessory meristems in the leaf axils. Epicormic bud strands, the same as those responsible for proventitious buds, multiply in them in profusion. When the aerial portion of a young plant is destroyed the buds in the lignotuber allow it to reshoot. The lignotubers on *E.melliodora*, especially on younger plants, are quite obvious (see, Fig. 3.5.). Although the stem swelling is obvious on *E.viminalis* seedlings once they have been planted there is no obvious sign of the lignotuber as on the *E.melliodora*. Some trees do not produce a lignotuber but rather carrot-like swellings near the junction of the root and shoot. The normal epicormic strands are present but they do not proliferate as they do in lignotubers. The species which do not develop lignotubers occur mostly in moist localities (Jacob, 1951). This appears to apply to

FIG. 3.5: Lignotuber on a young *E.melliodora*

E.viminalis populations from high rainfall areas (Ladiges and Ashton, 1974).

3.2 Growth Parameters:

In the growth of any vascular plant and especially in woody plants there are two different types of growth, elongative and girth growth. Elongative growth involves the elongation of the plant stem and is caused by cell division and cell elongation in a region just below the stem apex, namely, the 'primary elongation zone'. In trees such as the eucalypts being studied, this growth can be followed by measuring the height of the main stem or 'dominant leader'. During the early life of most trees the stem being dominant leader may change several times as a result of damage and loss. The increase in stem length or height is termed 'primary growth'.

Girth growth is caused by the development of additional vascular tissue and is termed 'secondary growth'. The new tissue develops in the vascular cambium, a region of meristematic tissue. The periodic activity of the vascular cambium, when growing conditions permit, is responsible for the growth rings in the wood of trees growing in temperate regions. Secondary growth can be assessed by measuring the stem diameter changes.

The activation of the secondary growth follows the onset of the primary growth in each growing period. The stimulation of the primary growth is caused by suitable environmental conditions, mainly temperature and day length, and the attendant production of gibberellins. Cambial activity is apparently triggered by hormones produced by the growing buds.

3.3 Measurement of the Growth Parameters:

The height and stem diameter of the eucalypts planted in the experimental plantation in January, 1980, were measured on a monthly basis from April, 1980 until March, 1982. The height and stem diameter of the trees that were not 'established' were measured until May,1982 to complete a one year period.

Height: Height was measured using 1.5m aluminium height sticks. The topmost stick was marked in 20mm intervals. Within one year of planting some of the trees were over 5m tall and two people were required to measure the tree's height to avoid parallax error.

Stem Diameter: Stem diameter was measured using a vernier caliper and recorded to the nearest 0.1mm. It was measured at 0.25m above the ground level and this height was marked on the stem to ensure that the same place was measured on each occasion.

3.4. Presentation of Data:

In the Tables in this Chapter describing height and stem diameter growth, data has been presented in two ways. Firstly, as average height or average stem diameter measurements in metres or millimetres, respectively, and secondly, in terms of the trees' average relative growth rate. The latter has been used as it represents the efficiency of the plant as a producer of raw materials and so was less variable than the incremental increases in height or stem diameter.

The formula for average relative growth rate is,

$$\bar{R}_{1-2} = \frac{\ln A_2 - \ln A_1}{T_2 - T_1} \qquad (1)$$

where A_1 = height or stem diameter at T_1 and A_2 = height or stem diameter at T_2. To make relative growth rate more readily interpreted, after calculation and analysis, it was converted to a percentage increase per unit time. The formula being,

$$PRG = (e^{(\bar{R})} \times 100) - 100 \qquad (2)$$

where PRG = percentage relative growth. This conversion of relative growth rate gives the same result as the calculation,

$$\left(\frac{A_2}{A_1} \times 100\right) - 100 \qquad (3)$$

3.5 Height and Stem Diameter Growth After One and Two Years:

3.5.1 Height:

The heights of those *E.viminalis* and *E.melliodora* that were sprayed (irrigated and not irrigated) and not sprayed (irrigated and not irrigated) after one and two years after the "establishment" period are presented in Table 3.1. The trees that were established, sprayed and irrigated, supposedly having had the best growing conditions, were the control.

The measurements recorded in Table 3.1 show that *E.melliodora* did not have the same fast height growth rate as *E.viminalis*.

TABLE 3.1

Tree Height

	E. viminalis Average Height (m)	*E. viminalis* Percentage Rel. Growth	*E. melliodora* Average Height (m)	*E. melliodora* Percentage Rel. Growth
Established				
Sprayed & Irrigated				
Start	1.22	-	0.73	-
Year 1	3.56	196	1.39	90
Year 2	5.61	56	1.97	42
Total	-	359	-	170
Sprayed, not Irrigated				
Start	1.22	-	0.69	-
Year 1	3.45	183	1.29	87
Year 2	5.45	58	1.90	47
Total	-	347	-	175
Not Sprayed, Irrigated				
Start	0.95	-	0.53	-
Year 1	2.81	196	1.09	105
Year 2	4.76	69	1.68	54
Total	-	401	-	216
Not Sprayed, not Irrigated				
Start	0.98	-	0.55	-
Year 1	2.84	191	1.11	102
Year 2	5.05	77	1.64	48
Not Established				
Not Sprayed, not Irrigated				
Start	0.68	-	0.43	-
Year 1	1.66	144	0.89	107

<u>Height Measurements for the Control</u>: The control *E.viminalis* was about 2.85 times the height of the *E.melliodora* by the end of the study. The total percentage relative growth was more than twice that of the *E.melliodora*. Both of these differences were significant. At planting, the trees' average height were about 0.31m and 0.18m for *E.viminalis* and *E.melliodora*, respectively. This indicates a 1700% increase in height in the *E.viminalis* and a 1000% increase in *E.melliodora*. Over the two years, *E.melliodora* increased its height by 0.66m in the first year but only 0.58m in the second. This compares with the decrease in growth by *E.viminalis* from 2.34m in the first year to 2.05m in the second.

<u>Height Measurements of the Treatments</u>:

<u>Comparison of Final Height with Control</u>: Of the height measurements, after two years, recorded in Table 3.1, the average height of those *E.melliodora* unirrigated and unsprayed was the only measurement significantly less than that of the control. While the average height was significantly less, the total percentage relative growth was not. This suggests that they grew as successfully as the control but their final height was reduced as a result of their smaller initial height.

The average height of those *E.viminalis* that were not established, after one year, was 1.9m less than that of the control trees. This and the reduced percentage relative growth were significantly less than the control. The average height of the *E.melliodora* was also significantly less than that of the control, but the percentage relative growth was not significantly different.

Comparison of *E.viminalis* and *E.melliodora* Heights: Similarly to the control, the unirrigated *E.viminalis* was about 2.87 times the final height of the *E.melliodora* and had nearly twice the percentage relative growth. This suggests that when established and sprayed, the species will grow to the same heights in relation to one another whether irrigated or not. The final height of the unsprayed *E.viminalis* was 2.83 and 3.08 times greater than that of the *E.melliodora* when irrigated and not irrigated, respectively.

The difference between the average height of those *E.viminalis* and *E.melliodora* that were not established was significantly less than that for the control. After one year the *E.viminalis* was only 1.87 times higher than the *E.melliodora* which corresponds to 2.56, 2.67, 2.58 and 2.56 times after one year for the sprayed (irrigated and unirrigated) and unsprayed (irrigated and unirrigated) trees, respectively. Also, whereas in the control the total percentage relative growth of the *E.viminalis* was over 100% greater than the *E.melliodora*, the difference for the unestablished trees was only 26%.

Comparison of Growth in the First and Second Years: The sprayed but unirrigated *E.viminalis* was similar to the control, growing more in the first year than in the second. Although the average annual increase in height by the *E.melliodora* was slightly less than the control, it was more constant, with 0.6m growth in the first year and 0.61m in the second.

The annual height increase for the unsprayed *E.viminalis* was greater in the second year than in the first whether irrigated or not. Whereas the increase in height was greater in the second year for the irrigated *E.melliodora*, it was slightly less in the second year for those that were unirrigated.

3.5.2 <u>Stem Diameter</u>:

The average stem diameters of the trees at the end of their first and second years of growth are given in Table 3.2.

<u>Stem Diameter Measurements of the Control</u>: Although the average final stem diameter of the control *E.viminalis* was about 2.2 times that of the *E.melliodora*, the total percentage relative growth of the latter was significantly greater. In both species the increase in stem diameter was greater in the second year than in the first.

<u>Stem Diameter Measurements of the Treatments</u>: Of the average stem diameter measurements, after two years, recorded in Table 3.1 none were significantly different from the control. However, the percentage relative growth of both *E.viminalis* and *E.melliodora* when unsprayed was, whether irrigated or not, significantly higher.

The average stem diameters of both the *E.viminalis* and *E.melliodora* that were not established were, after one year, significantly less than the control. While the total percentage relative growth of the *E.viminalis* was

TABLE 3.2

Stem Diameter

	E.viminalis Average Stem Diameter (mm)	*E.viminalis* Percentage Rel.Growth	*E.Melliodora* Average Stem Diameter (mm)	*E.Melliodora* Percentage Rel.Growth
Established				
Sprayed & Irrigated				
Start	14.1	-	5.5	-
Year 1	51.8	267	22.5	306
Year 2	92.4	79	42.1	90
Total	-	555	-	669
Sprayed, not Irrigated				
Start	15.0	-	5.3	-
Year 1	50.2	235	20.0	278
Year 2	89.1	77	38.3	92
Total	-	493	-	624
Not Sprayed, Irrigated				
Start	8.6	-	3.3	-
Year 1	44.0	410	14.8	348
Year 2	93.8	114	38.8	164
Total	-	991	-	1082
Not Sprayed, not Irrigated				
Start	8.6	-	3.3	-
Year 1	45.4	431	17.0	447
Year 2	94.9	208	41.9	148
Total	-	1002	-	1260
Not Established				
Not Sprayed, not Irrigated				
Start	5.6	-	2.8	-
Year 1	24.6	339	8.7	210

not significantly different from the control that of the *E.melliodora* was significantly less.

The final average stem diameter of the *E.viminalis* was 2.3, 2.4, and 2.3 times greater than that for the *E.melliodora* for those trees sprayed and unirrigated, unsprayed and irrigated and unsprayed and unirrigated, respectively. The total percentage relative growth of the *E.melliodora* was greater than that of the *E.viminalis* in all treatments, except for those trees that were unestablished.

Similarly to the control, there was more stem diameter growth for both *E.viminalis* and *E.melliodora* in the second year than in the first, in all of the treatments.

3.5.3 Stem Diameter/Height Ratio:

During the assessment of shelter belt plantations prior to this study it was found that trees of the same species in differing sites sometimes showed differing growth forms. The ratio between the stem diameter and the height was found to be a useful way of expressing these differences. In the case of a tall tree with a slender trunk the ratio is lower than for a more spreading tree with a thicker, and usually shorter, trunk. For a sapling a lower ratio can indicate that the tree is increasing its height faster than its stem diameter. A ratio of 0.016, for instance, indicates that for every metre of height, the tree has put on 16mm of stem diameter.

So as to be able to statistically analyse this ratio it was determined as: $\ln_{SD} - \ln_{H}$, where SD is stem diameter and H is height. The exponential of the result, being the same as SD/H, is used in the Tables.

The stem diameter/height ratios of those trees described in Tables 3.1 and 3.2 are presented in Table 3.3.

TABLE 3.3

Stem diameter/height

	E.viminalis Stem diameter/height	*E.melliodora* Stem diameter/height
Established		
Sprayed & irrigated		
Start	0.012	0.008
Year 1	0.015	0.016
Year 2	0.016	0.021
Sprayed,not irrigated		
Start	0.012	0.007
Year 1	0.014	0.016
Year 2	0.016	0.020
Not sprayed,irrigated		
Start	0.009	0.006
Year 1	0.016	0.014
Year 2	0.020	0.024
Not sprayed, not irrigated		
Start	0.009	0.007
Year 1	0.016	0.015
Year 2	0.019	0.026
Not Established		
Not sprayed, not irrigated		
Start	0.009	0.007
Year 1	0.015	0.010

The stem diameter/height ratio of the control *E.viminalis* was significantly greater than that of the *E.melliodora* at the start of the measurements (April, 1980) and significantly less by the end of the study (March, 1982). This was the same for those trees sprayed but not irrigated, with the stem diameter/height ratios for both species not being different from the control.

While the stem diameter/height ratios of those *E.viminalis* that were not sprayed (whether irrigated or not) were still lower than that of the *E.melliodora*, they were significantly higher than that of the control as were the *E.melliodora*.

Although the height and stem diameter of those *E.viminalis* that were not established were significantly less than that of the control, the stem diameter/height ratio was not significantly different. However, the ratio for the *E.melliodora* was significantly less than the control.

3.5.4 Summary:

Given a three month period of establishment and having been sprayed for insects, the *E.viminalis* maintained a rapid growth rate both in height and stem diameter and easily outgrew *E.melliodora*. This applied with or without irrigation. When the *E.viminalis* were established but not sprayed, they still grew rapidly - again with or without irrigation. However, from the stem diameter/height ratio the effect of the insect damage on the trees may eventually change the *E.viminalis'* growth form.

The lack of the three month period of establishment had the most noticeable effect on the growth of *E.melliodora* and *E.viminalis*. The average height and stem diameter of both species were significantly less than the control after one year's growth.

3.6 Height and Stem Diameter Growth of Wind-Protected Trees:

The height and stem diameter measurements of the wind-protected trees are summarised in Table 3.4.

Table 3.4

	Average Height (m)	Percentage Rel.Growth	Average Stem Diameter (mm)	Percentage Rel.Growth	Stem Diameter Height Ratio
			E.viminalis		
Start	0.86	-	8.7	-	0.010
Year 1	2.84	230	39.2	357	0.014
Year 2	5.10	80	78.7	101	0.015
Total	-	493	-	802	-
			E.melliodora		
Start	0.55	-	3.3	-	0.005
Year 1	1.16	111	15.7	382	0.014
Year 2	1.94	67	39.1	136	0.019
Total	-	253	-	1037	-

The final average tree heights of both the *E.viminalis* and *E.melliodora* were not significantly different from the control. The percentage relative height growth of the *E.melliodora* was, however, significantly greater.

The average height of the *E.viminalis* was about 2.6 times that of the *E.melliodora*, and for both species the increase in height was greater in the second year than in the first.

Although the final average stem diameters of both species were not significantly different from the control, the percentage relative growth was significantly greater. The average stem diameter of the *E.viminalis* was about twice that of the *E.melliodora* and, like the height, increased more in the second year than in the first. The stem diameter/height ratio for both species was not significantly different from the control.

Although the height and stem diameter of the wind-protected trees were not significantly different from the control, the percentage relative growth differences suggests a possible advantage for *E.melliodora*, when the trees are wind-protected.

3.7 <u>Height and Stem Diameter Growth of Frost-Protected Trees</u>:

The average heights and stem diameters for the frost-protected trees are summarised in Table 3.5.

TABLE 3.5

	Average Height (m)	Percentage Rel.Growth	Average Stem Diameter (mm)	Percentage Rel.Growth	Stem diameter/ Height Ratio
			E.viminalis		
Start	1.27	-	14.1	-	0.011
Year 1	3.65	187	51.8	266	0.014
Year 2	6.11	67	98.0	89	0.016
Total	-	381	-	584	-
			E.melliodora		
Start	0.73	-	5.4	-	0.007
Year 1	1.36	86	21.5	298	0.015
Year 2	2.41	77	43.5	102	0.018
Total	-	230	-	706	-

As the trees were protected from frost for the first year only, a comparison with the control can only be made for that period. Neither the average height nor stem diameter were significantly different from the control for both species in the first year. This also applied for the percentage relative growth.

The results did not suggest that frost protection gave any advantage to either species.

3.8 Height and Stem Diameter Growth of Mulched and Unmulched Trees:

The mulched and unmulched plots were a secondary part of this study to determine the effect of the horticultural practice of mulching. They also provided further replication for irrigated and unirrigated trees. The control for this experiment was also those trees that were established, sprayed, irrigated and unmulched. The measurements are summarised in Tables 3.6 (*E.viminalis*) and 3.7 (*E.melliodora*).

As in Tables 3.1 and 3.2, the average heights and stem diameters of the *E.viminalis* were, in all treatments, significantly greater than those of the *E.melliodora*. The total percentage relative height growth of the *E.viminalis* was greater than that of *E.melliodora* and the total percentage relative stem diameter growth of the latter was greater than the former.

3.8.1 Height:

For *E.viminalis* there was no significant difference between any of the treatments, both in average height or in percentage relative growth. The increase in height

TABLE 3.6

Growth of Mulched and Unmulched *E.viminalis*

	Average Height (m)	Percentage Rel.Growth	Average Stem Diameter (mm)	Percentage Rel.Growth	Stem Diameter Height Ratio
Not Mulched					
Irrigated					
Start	1.10	-	14.2	-	0.012
Year 1	3.39	208	53.2	276	0.015
Year 2	5.54	63	99.6	87	0.018
Total	-	404	-	603	-
Not irrigated					
Start	1.07	-	12.2	-	0.010
Year 1	3.02	180	43.5	257	0.014
Year 2	4.96	65	86.0	98	0.017
Total	-	364	-	607	-
Mulched					
Irrigated					
Start	0.99	-	11.6	-	0.011
Year 1	3.24	227	50.7	339	0.015
Year 2	5.62	74	93.2	84	0.017
Total	-	468	-	706	-
Not Irrigated					
Start	1.10	-	13.8	-	0.012
Year 1	3.30	200	51.3	272	0.014
Year 2	5.47	66	92.7	81	0.017
Total	-	398	-	571	-

TABLE 3.7

Growth of Mulched and Unmulched *E.melliodora*

	Average Height (m)	Percentage Rel.Growth	Average Stem Diameter (mm)	Percentage Rel.Growth	Stem Diameter Height Ratio
Not Mulched					
Irrigated					
Start	0.66	-	3.8	-	0.006
Year 1	1.31	98	19.1	402	0.015
Year 2	1.94	48	40.2	110	0.021
Total	-	194	-	954	-
Not Irrigated					
Start	0.76	-	5.4	-	0.007
Year 1	1.38	82	21.6	301	0.016
Year 2	2.12	54	43.5	102	0.021
Total	-	179	-	709	-
Mulched					
Irrigated					
Start	0.53	-	3.4	-	0.006
Year 1	1.31	147	17.7	427	0.014
Year 2	2.15	64	41.4	134	0.019
Total	-	306	-	1134	-
Not Irrigated					
Start	0.73	-	5.1	-	0.00
Year 1	1.31	79	21.0	311	0.016
Year 2	2.16	65	44.8	113	0.021
Total	-	196	-	776	-

was greater in the first year than in the second for all of the *E.viminalis*, except for those that were mulched and irrigated. The average heights of the *E.melliodora* were also not affected by the treatments but the total percentage relative growth of those trees mulched and irrigated was significantly greater than for any of the other treatments. Unlike the *E.viminalis*, the height of the *E.melliodora* increased more in the second year than in the first, except for those trees that were irrigated but not mulched.

3.8.2 Stem Diameter:

As with height none of the treatments significantly affected the average stem diameters or percentage relative growth of the *E.viminalis*. The stem diameter increased more in the second year than in the first for all the treatments. The average stem diameter of the *E.melliodora* was also not affected by any of the treatments, but the percentage relative growth of those trees that were irrigated was significantly greater than those not irrigated whether mulched or not. The stem diameter of the *E.melliodora* also increased more in the second year than in the first.

3.8.3 Stem Diameter/Height:

The final stem diameter/height ratio was higher for *E.melliodora* than *E.viminalis* in all treatments. The ratios were not affected by any of the treatments.

3.8.4 Summary:

The average heights and average stem diameters of both *E.viminalis* and *E.melliodora* were not significantly affected by mulching or irrigation when they had been established and were sprayed for insects. In regard to the effect of irrigation this agrees with the results in Tables 3.1 and 3.2. However, the significantly greater total percentage growth for those *E.melliodora* that were mulched and irrigated does suggest an advantage to the species from this treatment.

CHAPTER FOUR

MEASUREMENTS OF SEASONAL GROWTH AND RELATED EXPERIMENTS. OBSERVATIONS AND RESULTS

4.1

As both average temperature and day length in Canberra vary greatly from June to December, the seasonal changes in plant growth can be expected to be likewise cyclical. The trees in the experimental plantation were measured on a monthly basis so that their growth cycles, both in height and stem diameter could be closely followed for the two year period.

4.2 Results:

Seasonal growth data for the trees is presented in two ways. The first is growth per month expressed as a percentage of the total growth. The second is percentage growth in each month relative to the previous month. The first was particularly useful when making comparisons between treatments and with other studies (e.g. Specht and Brouwer, 1975) and the second was found to be a more sensitive growth measure than monthly increase in height or stem diameter increments.

The seasonal growth of those trees whose total growth is summarised in Tables 3.1 and3.2 is presented in Tables 4.1 and 4.2 and in Figs. 4.1 to 4.11.

TABLE 4.1

Height Growth Per Month as a Percentage of Total Growth

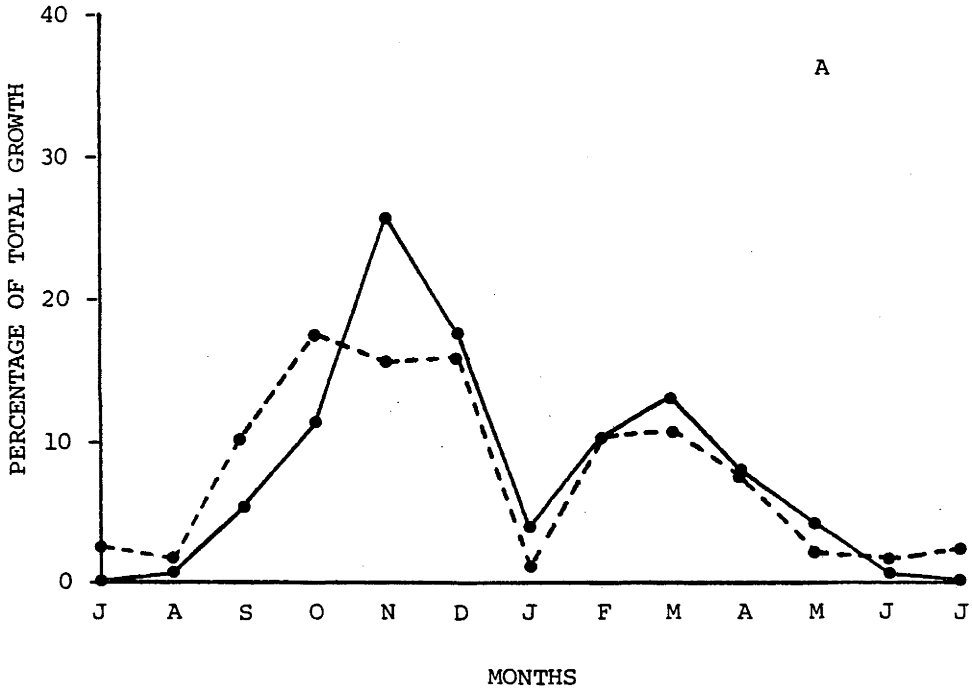
	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Established												
Sprayed & irrigated												
E. viminalis	4.1	10.0	13.3	7.7	4.1	0.7	0.3	0.5	5.2	11.0	25.7	17.8
E. melliodora	7.1	13.5	15.1	4.84	0	0	0	-2.4	4.0	16.7	34.9	13.5
Sprayed, not irrigated												
E. viminalis	1.9	11.4	14.0	5.7	2.4	1.7	1.2	1.2	3.8	12.8	28.0	16.3
E. melliodora	5.0	8.0	7.4	5.0	0.9	0.9	0	0.9	3.3	24.0	33.1	14.9
Not sprayed, irrigated												
E. viminalis	5.0	14.4	18.4	4.0	2.1	1.8	0.8	0.8	7.6	11.6	16.3	17.3
E. melliodora	3.4	6.0	17.1	5.1	0	0	0	1.7	0	21.4	36.8	8.6
Not sprayed, not irrigated												
E. viminalis	4.2	13.6	15.0	3.0	1.3	0.5	1.0	1.2	6.9	14.3	25.1	14.3
E. melliodora	0	14.7	10.1	3.7	0	0	0	-0.9	3.7	21.1	32.1	15.6
Not Established												
Not sprayed, not irrigated												
E. viminalis	-2.0	5.1	14.3	13.3	3.1	3.1	2.0	3.1	16.3	30.6	9.2	2.0
E. melliodora	8.7	15.2	2.2	4.4	2.2	0	0	2.2	6.5	19.6	32.6	10.9

TABLE 4.2

Stem Diameter Growth Per Month as a Percentage of Total Growth

	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Established												
Sprayed & irrigated												
E.viminalis	1.2	11.2	11.9	7.7	2.1	2.0	2.5	1.9	10.7	17.6	15.4	15.8
E.melliodora	7.8	7.7	14.9	5.3	0.8	0.5	-1.1	1.9	7.5	16.7	14.7	23.3
Sprayed, not irrigated												
E.viminalis	3.1	6.9	12.0	7.3	5.1	2.0	2.0	2.2	10.7	18.0	16.4	14.2
E.melliodora	4.5	6.4	10.3	7.8	2.3	1.7	0.8	0.9	9.9	14.3	22.6	18.6
Not Sprayed, irrigated												
E.viminalis	6.0	11.1	7.5	7.1	6.6	3.0	1.8	3.0	8.2	16.0	12.3	17.4
E.melliodora	7.9	9.4	15.2	6.3	4.4	0.3	0.1	-0.4	5.4	14.9	10.1	26.6
Not sprayed,not irrigated												
E.viminalis	8.7	6.3	9.0	7.5	4.4	1.5	1.3	2.9	9.9	16.7	10.3	21.5
E.melliodora	10.7	12.8	13.7	4.4	2.2	0.3	0	0.6	6.2	14.7	12.7	22.0
Not Established												
Not sprayed, not irrigated												
E.viminalis	6.4	12.3	6.6	9.9	2.9	3.8	2.4	0.7	11.4	21.0	7.7	14.9
E.melliodora	13.4	9.4	12.8	11.6	-9.8	3.9	1.2	0.9	10.3	22.1	10.5	13.7

FIG. 4.1: The height (•——•) and stem diameter (•-----•) growth per month of the control *E.viminalis* (A) and *E.melliodora* (B) as a percentage of total growth.


40
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PERCENTAGE OF TOTAL GROWTH
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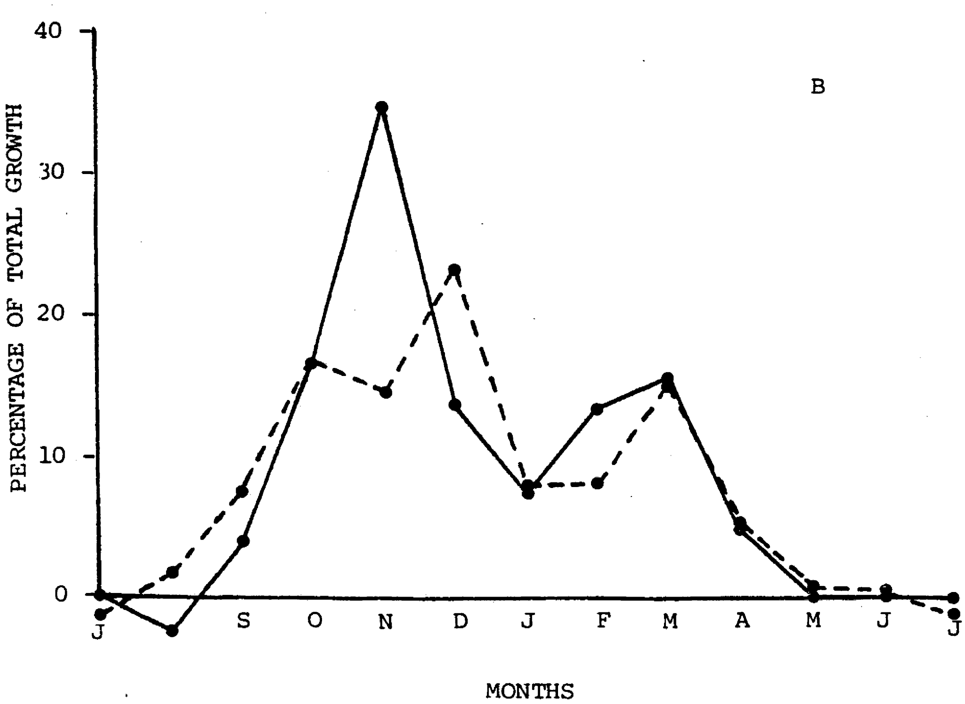
J A S O N D J F M A M J J
MONTHS


40
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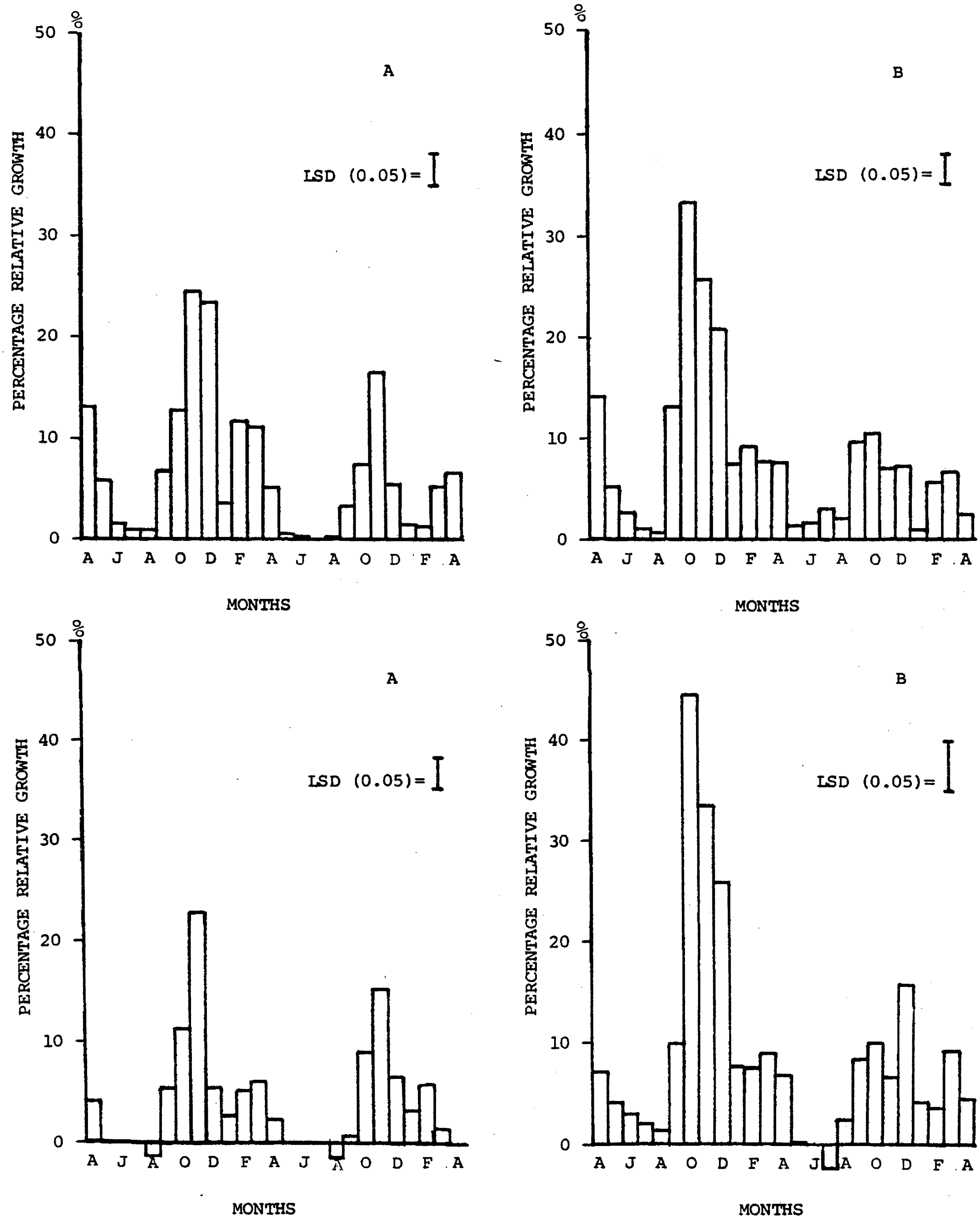
PERCENTAGE OF TOTAL GROWTH
B
J S O N D J F M A M J J
MONTHS

FIG. 4.2: Monthly percentage relative height (A) and stem diameter (B) growth of the sprayed and irrigated *E.viminalis*.

FIG. 4.3: Monthly percentage relative height (A) and stem diameter (B) growth of the sprayed and irrigated *E.melliodora*.



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LSD (0.05)=
PERCENTAGE RELATIVE GROWTH
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A
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LSD (0.05)=
PERCENTAGE RELATIVE GROWTH
%
0
10
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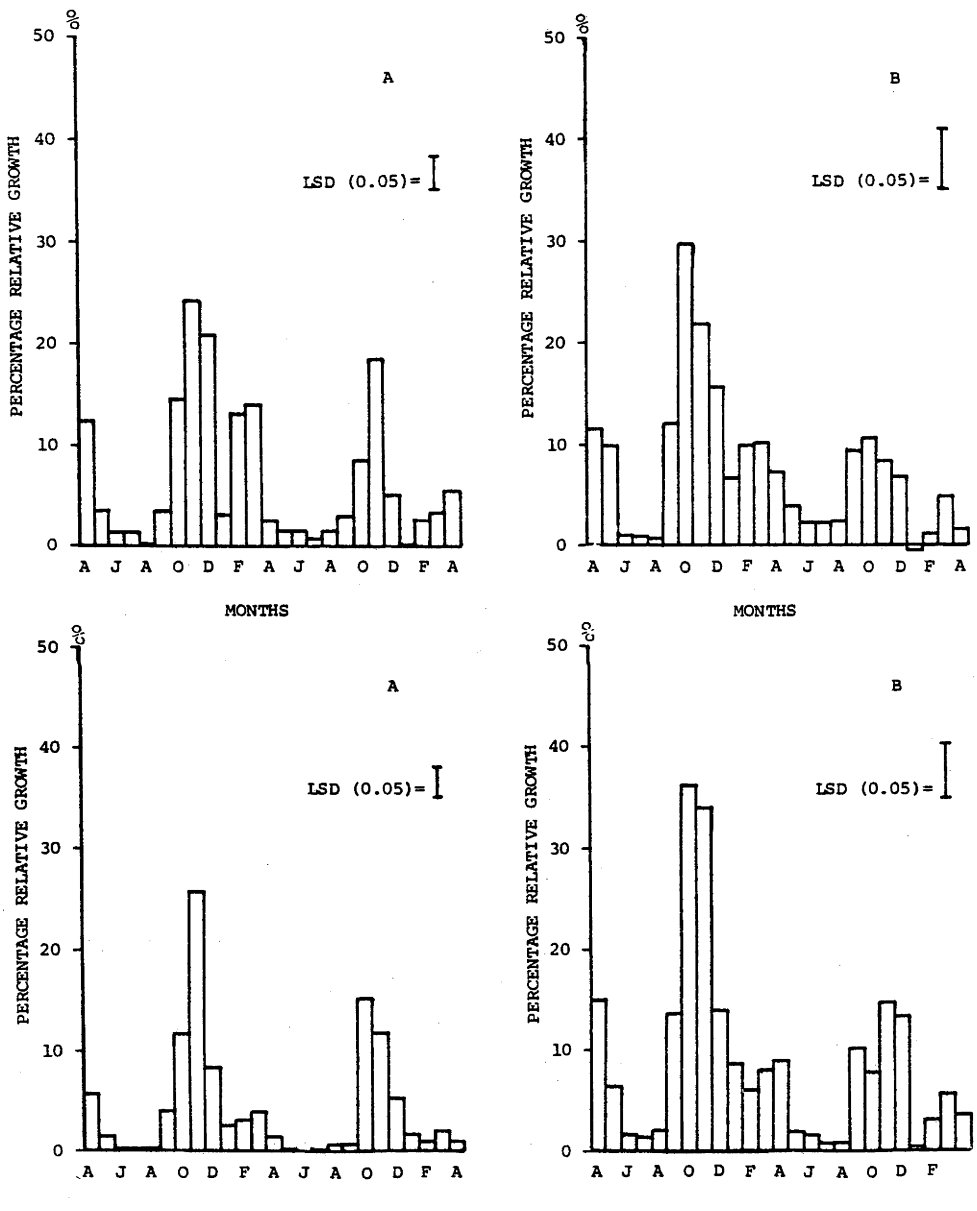
A J A O D F A J A O D F A
MONTHS

FIG. 4.4: Monthly percentage relative height (A) and stem diameter (B) growth of sprayed but unirrigated *E.viminalis*.

FIG. 4.5: Monthly percentage relative height (A) and stem diameter (B) growth of sprayed but unirrigated *E.melliodora*.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PERCENTAGE RELATIVE GROWTH
%
LSD (0.05)=
MONTHS
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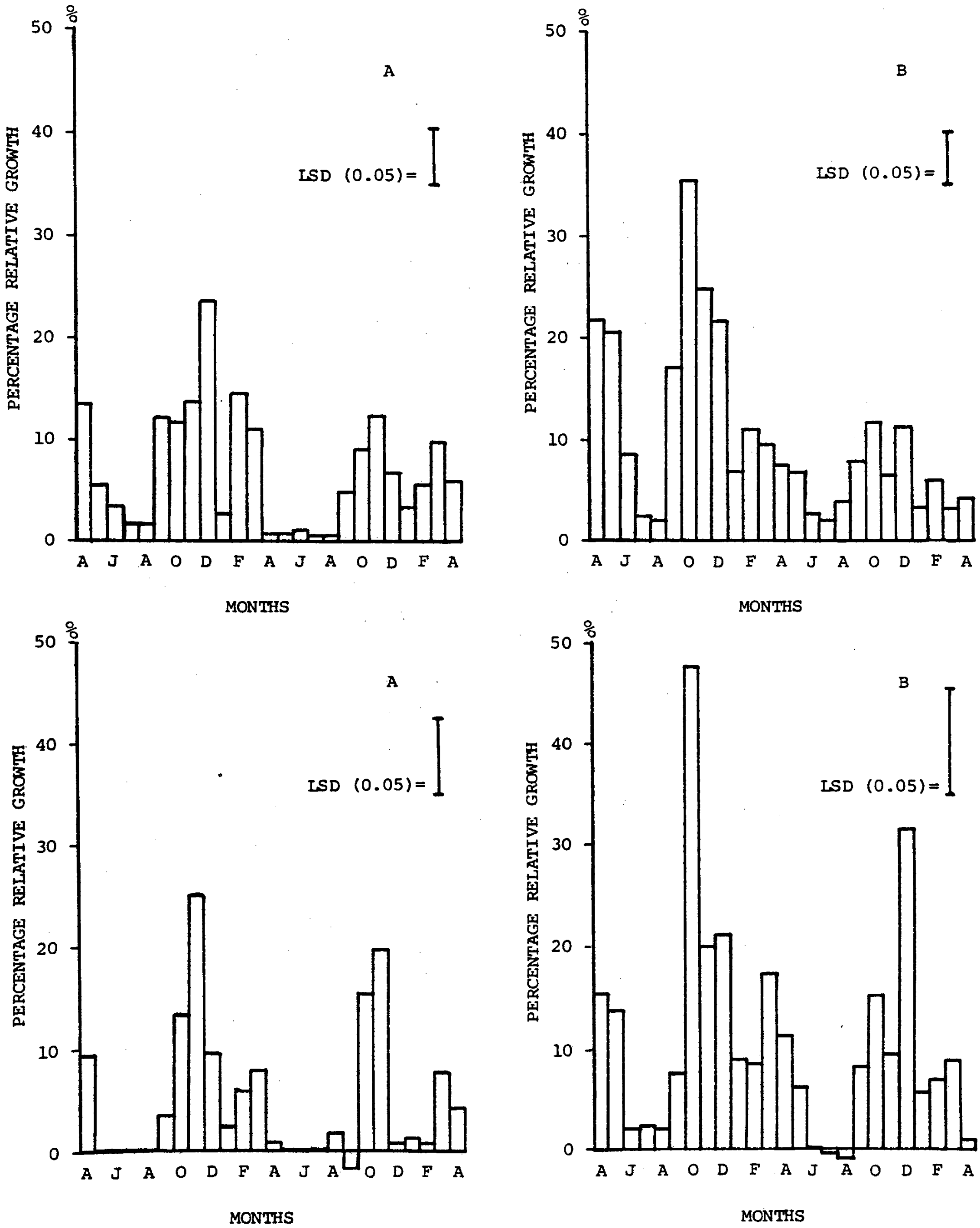
FIG. 4.6: Monthly percentage relative height (A) and stem diameter (B) growth of the unsprayed but irrigated *E.viminalis*.

FIG. 4.7: Monthly percentage relative height (A) and stem diameter (B) growth of the unsprayed but irrigated *E.melliodora*.



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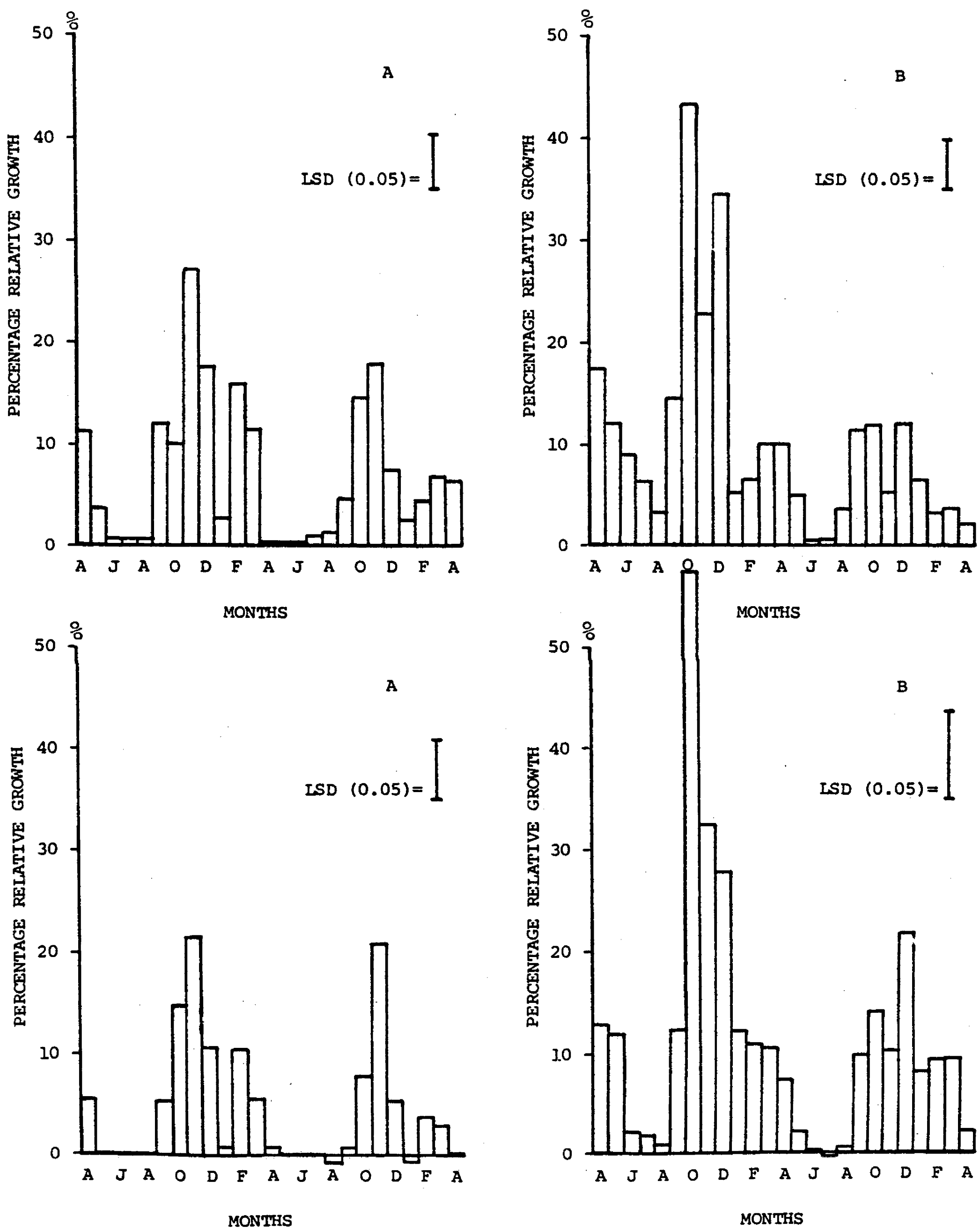
LSD (0.05)=
PERCENTAGE RELATIVE GROWTH
A J A O D F A J A O D F A
MONTHS

FIG. 4.8: Monthly percentage relative height (A) and stem diameter (B) growth of the unsprayed and unirrigated *E.viminalis*.

FIG. 4.9: Monthly percentage relative height (A) and stem diameter (B) growth of the unsprayed and unirrigated *E.melliodora*.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B
LSD (0.05)=
PERCENTAGE RELATIVE GROWTH
%
MONTHS
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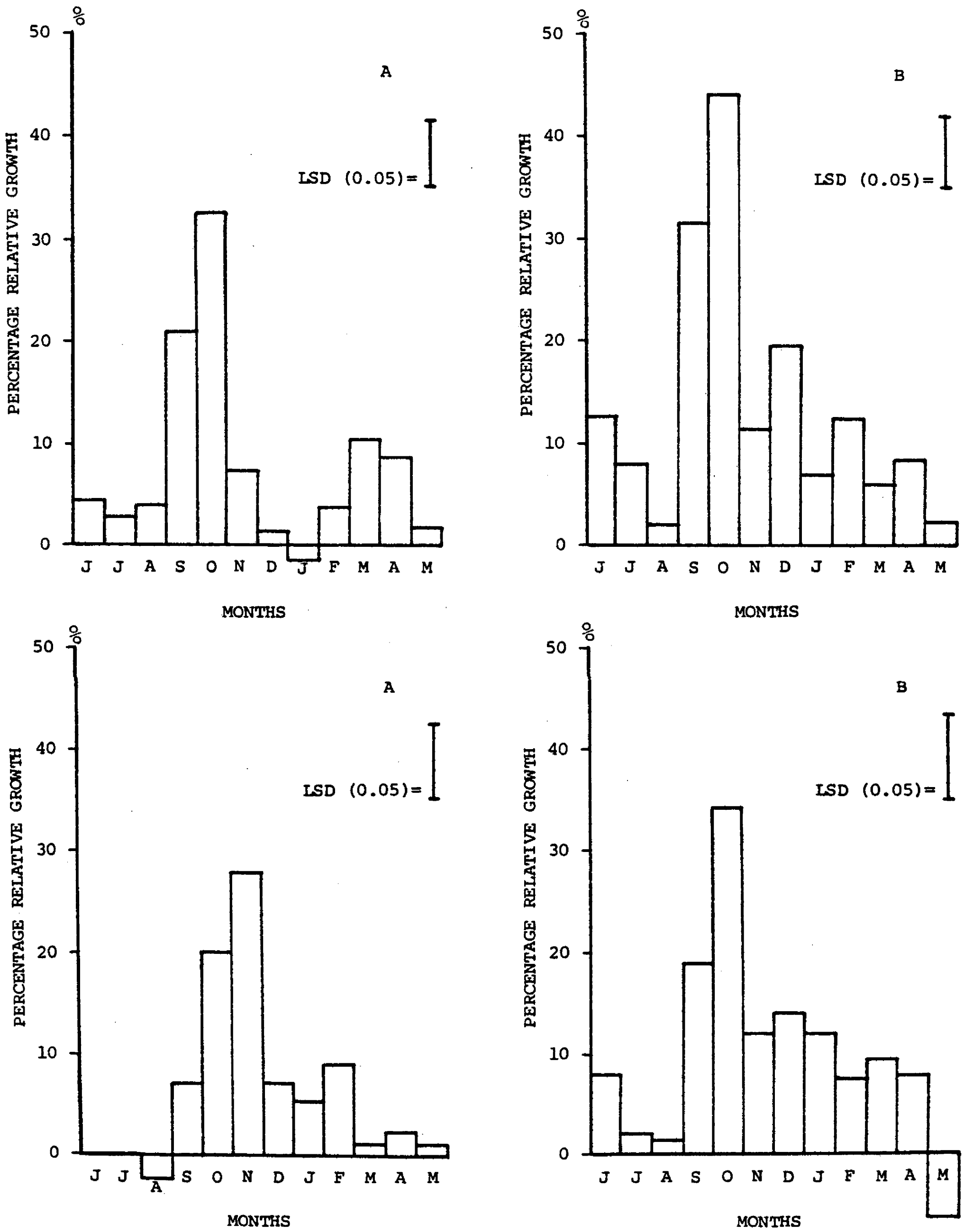
50

FIG. 4.10: Monthly percentage relative height (A) and stem diameter (B) growth of the unestablished *E.viminalis*.

FIG. 4.11: Monthly percentage relative height (A) and stem diameter (B) growth of the unestablished *E.melliodora*.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LSD (0.05)=
PERCENTAGE RELATIVE GROWTH
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J J A S O N D J F M A M
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B
LSD (0.05)=
PERCENTAGE RELATIVE GROWTH
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J J A S O N D J F M A M
MONTHS
A
LSD (0.05)=
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MONTHS
B
LSD (0.05)=
PERCENTAGE RELATIVE GROWTH
%
50
40
30
20
10
0
J J A S O N D J F M A M
MONTHS

4.2.1 Summary of the Results:

For both the *E.viminalis* and *E.melliodora* a distinctly bimodal rhythm in height and stem diameter growth was observed. The maximum growth occurred in October-December and February-March with reduced growth in January. There was little or no growth from May to August, inclusive. The main peaks for height growth were in November and March and for stem diameter growth in October (*E.viminalis*), December (*E.melliodora)* and March.

The reduction in height growth was greater for *E.melliodora* in the winter than for *E.viminalis* and the January decline was greater for *E.viminalis*. Any negative values for height growth for *E.melliodora* were confined to July or August whereas to January for *E.viminalis*.

The reduction in stem diameter growth was, as for height, greater for *F.melliodora* in winter and greater for *E.viminalis* in summer.

For sprayed trees the effect of not irrigating on seasonal growth was, in the case of *E.viminalis*, negligible, whereas for *E.melliodora* it resulted in obvious alternate growth peaks for height and stem diameter in the spring period.

When not sprayed but irrigated the seasonal height growth of *E.viminalis* was reduced in November but showed increase in March, whereas *E.melliodora's* height growth increased in November but was reduced in December-February. The stem diameter of neither species was obviously affected. When not sprayed and not irrigated the seasonal growth of the *E.viminalis* was not obviously affected although the stem diameter growth peaked in December rather than October. The *E.melliodora's* seasonal height growth although reduced in January and March did increase in October. The stem diameter growth was not obviously affected over the two year period.

As with total growth the lack of establishment had the most noticeable effect on seasonal growth. For *E.viminalis* the main height growth period was September-October with the growth peak in October, while the height growth of *E.melliodora* was markedly reduced in March. The stem diameter growth for both species was reduced in November-December with negative values in January (*E.viminalis*) and May (*E.melliodora*).

4.3 <u>The Effect of Wind-Protection on Seasonal Growth</u>:

The seasonal growth of those *E.viminalis* and *E.melliodora* that were wind-protected is summarised in Table 4.3, and the monthly percentage relative growth is presented in Figs.4.12 and 4.13.

The main differences between the seasonal height growth of the wind protected *E.viminalis* and the control was the reduced growth in December, 1980 and the increased growth in the following winter. The growth pattern was otherwise similar. As for seasonal stem diameter growth there was, again, basically the same pattern, but the total monthly relative growth was

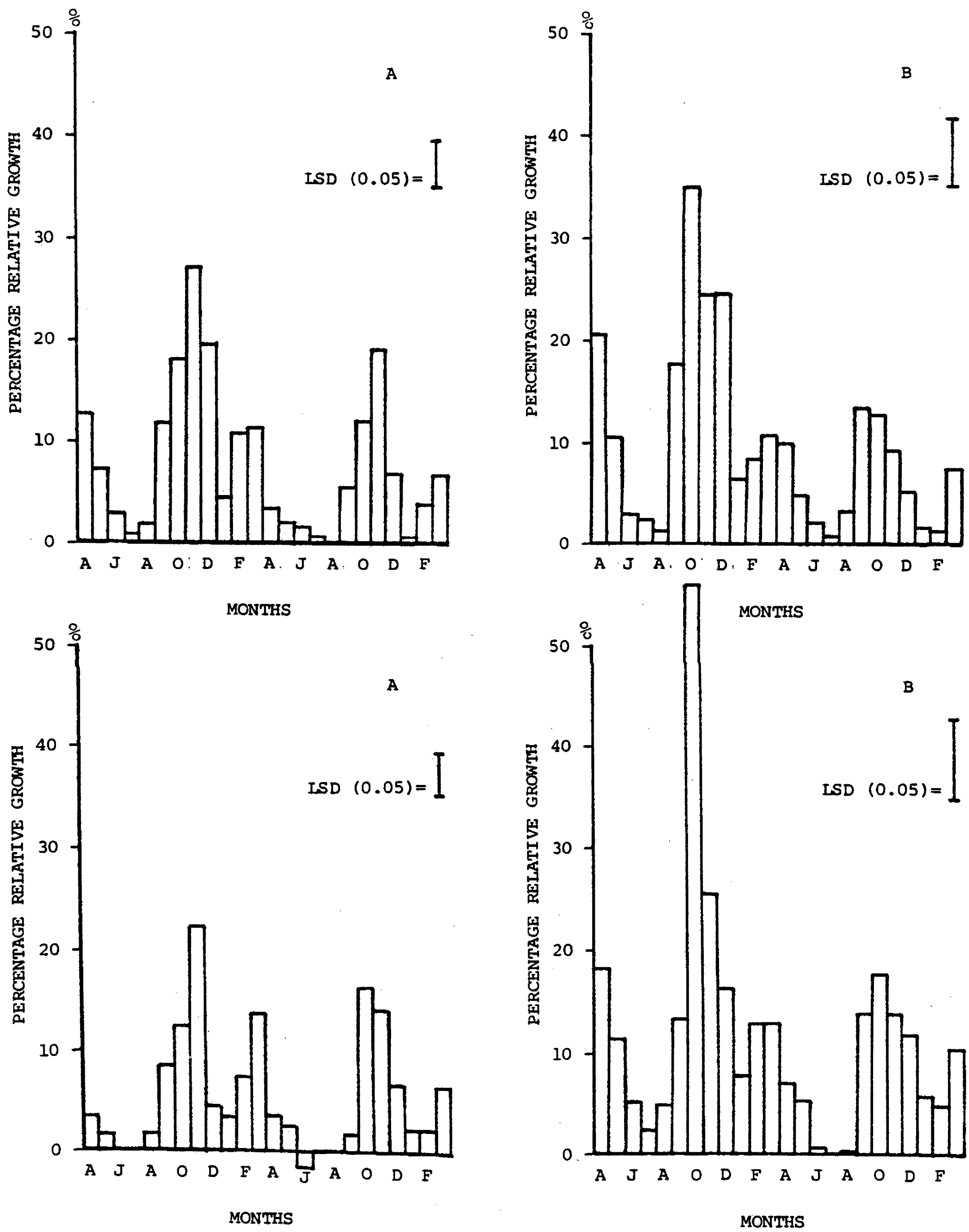
TABLE 4.3

Monthly Percentage of Total Growth

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Wind Protected												
E. viminalis												
Height	2.8	10.1	14.4	4.5	3.1	1.9	0.7	0.5	7.1	14.4	25.2	15.3
Stem Diameter	4.6	5.6	13.3	8.1	4.6	2.0	0.9	2.6	12.4	17.3	15.0	13.7
E. melliodora												
Height	5.0	7.9	18.7	4.3	2.2	-1.7	0	0.7	5.0	20.1	25.9	9.4
Stem Diameter	7.7	9.2	17.5	4.7	2.7	0.9	0.3	0.6	9.2	18.9	15.7	14.2
Frost Protected												
E. viminalis												
Height	2.7	11.2	16.3	6.8	3.1	1.0	0.4	1.2	4.6	12.0	25.8	12.8
Stem Diameter	2.8	7.9	11.7	9.0	6.0	2.6	1.3	4.1	8.5	17.5	13.4	15.1
E. melliodora												
Height	8.3	10.1	19.0	4.2	1.8	-1.8	0	0	1.8	15.5	25.6	15.5
Stem Diameter	7.6	10.8	13.4	7.6	0	3.4	0.3	-0.8	6.6	18.9	11.3	21.0
Mulched and Irrigated												
E. viminalis												
Height	4.9	13.1	17.2	4.2	3.8	1.1	0.6	1.3	7.2	13.6	21.6	12.1
Stem Diameter	5.5	7.4	12.1	8.9	4.0	2.1	0.9	0.6	8.7	17.5	14.8	17.0
E. melliodora												
Height	5.6	14.2	14.8	3.1	2.5	-0.6	0	0	4.9	16.7	27.2	12.4
Stem Diameter	7.6	11.0	12.9	5.3	2.6	0	-0.3	1.8	7.4	16.3	13.9	21.5

FIG. 4.12: Monthly percentage relative height (A) and stem diameter (B) growth of the wind-protected *E.viminalis*.

FIG. 4.13: Monthly percentage relative height (A) and stem diameter (B) growth of the wind-protected *E.melliodora*.


A
B
LSD (0.05)=
PERCENTAGE RELATIVE GROWTH
%
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MONTHS

greater in both years.

The wind-protected *E.melliodora* grew more in height than the control in the September-October period of both years, and also in March. The stem diameter growth started earlier in the year and was possibly continued for longer. Also, the stem diameter growth peak for the wind-protected trees was in October as compared to December for the control (Table 4.3).

4.4 The Effect of Frost-Protection on Seasonal Growth:

The seasonal growth of those *E.viminalis* and *E.melliodora* that were frost-protected is summarised in Table 4.3 and the monthly percentage relative growth is presented in Figs. 4.14 and 4.15.

Because the frost covers were only used for the first year comparisons with the control can only be made for that year. The only obvious differences for *E.viminalis* were the greater height growth in October, 1980, and the increased stem diameter growth in the June of the same year (Fig.4.14).

The seasonal growth of the *E.melliodora* was also similar to the control, except for height growth being recorded in May, 1981 and a negative value for height growth recorded in June of the same year.

4.5 The Effect of Combined Mulching and Irrigation on Seasonal Growth:

The seasonal growth of those *E.viminalis* and *E.melliodora* that were mulched and irrigated is summarised in Table 4.3 and the monthly percentage relative

FIG. 4.14: Monthly percentage relative height (A) and stem diameter (B) growth of the frost-protected *E.viminalis*.

FIG. 4.15: Monthly percentage relative height (A) and stem diameter (B) growth of the frost-protected *E.melliodora*.

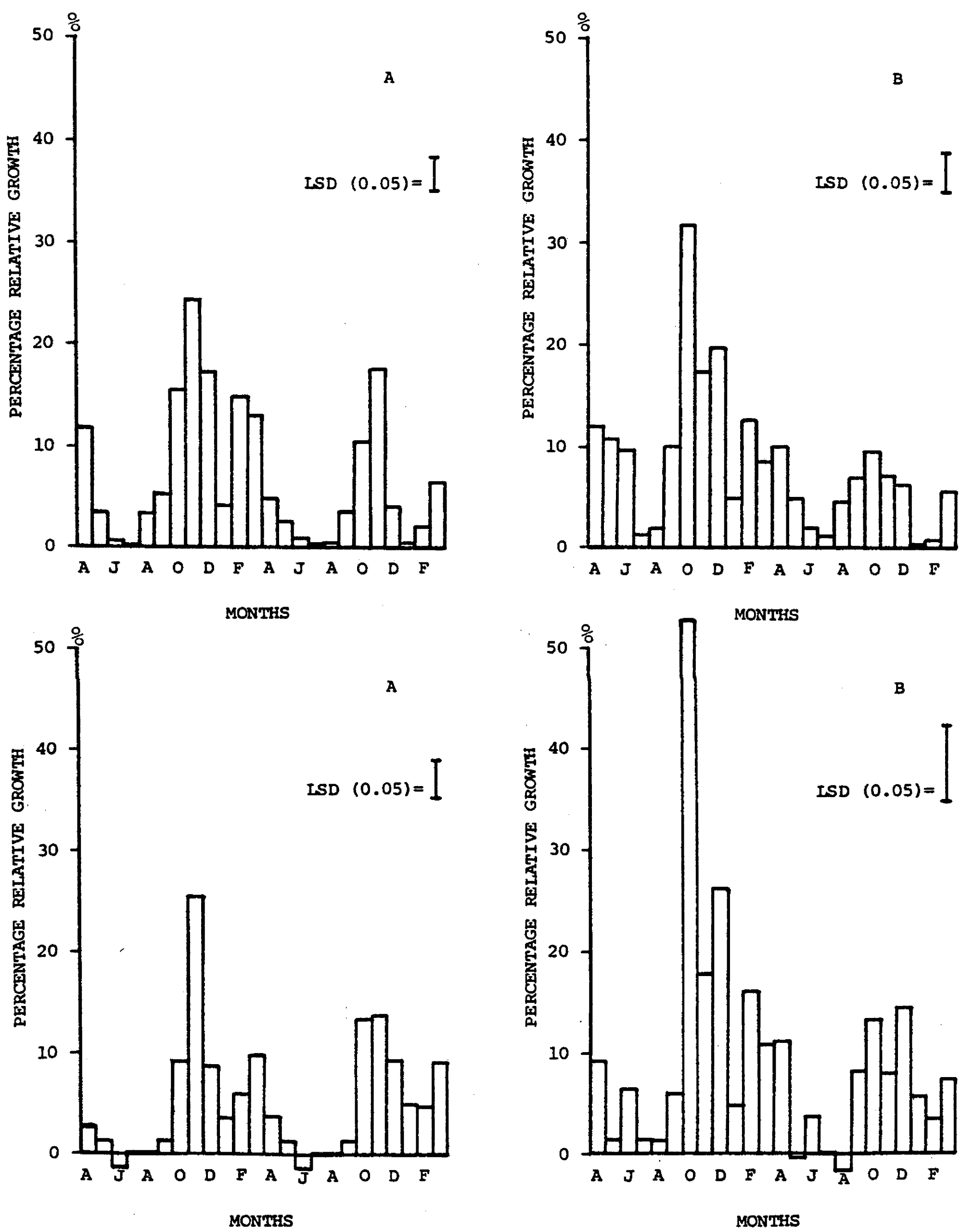
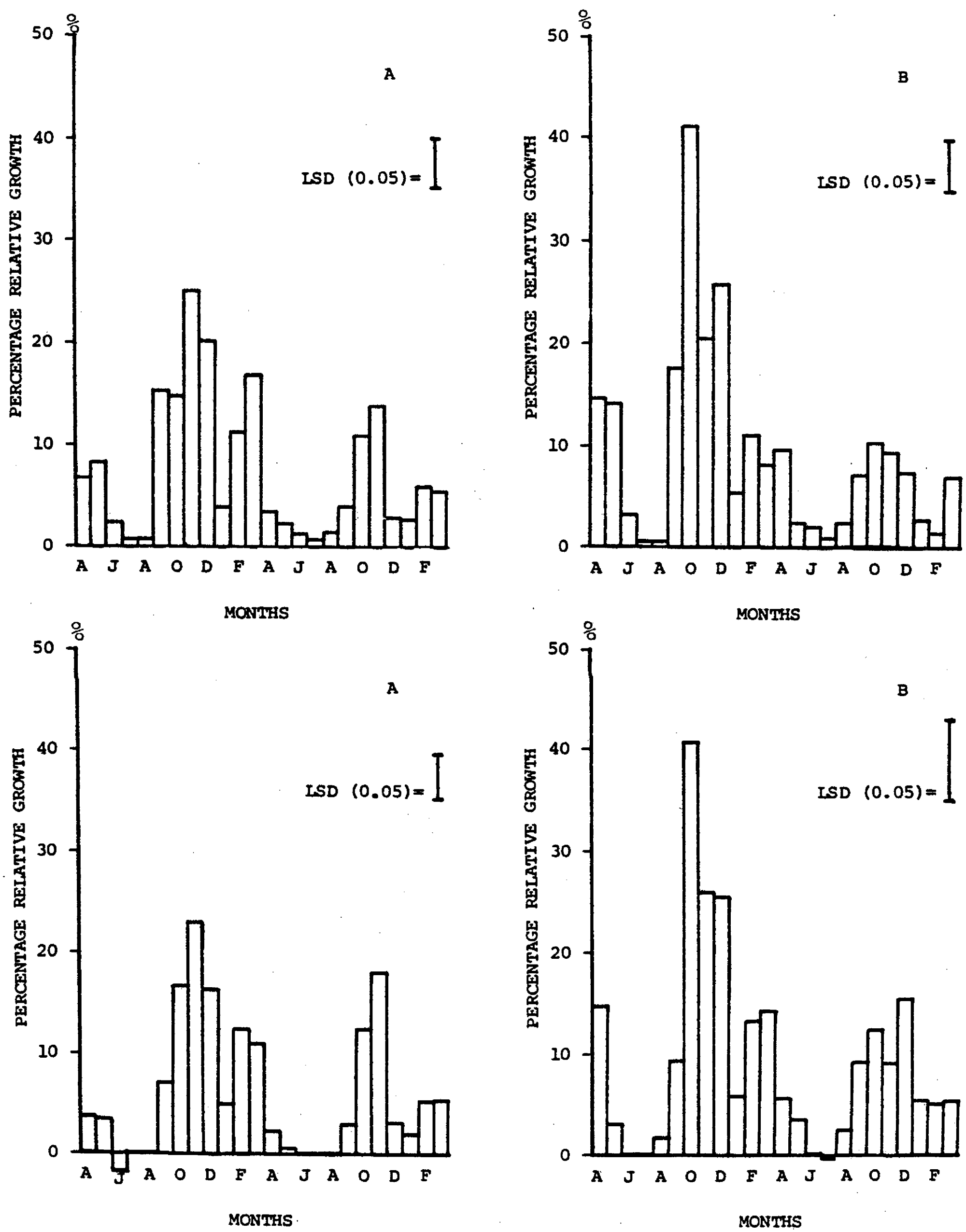

A
LSD (0.05)=
PERCENTAGE RELATIVE GROWTH
%
50
40
30
20
10
0
A J A O D F A J A O D F
MONTHS
B
LSD (0.05)=
PERCENTAGE RELATIVE GROWTH
MONTHS
A
LSD (0.05)=
PERCENTAGE RELATIVE GROWTH
MONTHS
B
LSD (0.05)=
PERCENTAGE RELATIVE GROWTH
MONTHS

FIG. 4.16: Monthly percentage relative height (A) and stem diameter (B) growth of the mulched and irrigated *E.viminalis*.

FIG. 4.17: Monthly percentage relative height (A) and stem diameter (B) growth of the mulched and irrigated *E.melliodora*.


A
B
A
B
LSD (0.05)=
PERCENTAGE RELATIVE GROWTH
%
0
10
20
30
40
50
A J A O D F A J A O D F
MONTHS

growth is presented in Figs. 4.16 and 4.17.

The seasonal height growth, when compared to the unmulched and irrigated control was similar, but there was increased growth in March.

The seasonal stem diameter growth was also similar to the control but there was increased growth in May and September. From Fig.4.16 increased height growth was seen in the September-October period in 1980 and in October, 1981. The increased May and September stem diameter growth was principally in 1980.

The seasonal height growth of the *E.melliodora* was the same as the control, as was the seasonal stem diameter growth (Table 4.3). From Fig. 4.17 the relative height growth was greater in most months. Although the stem diameter growth was less in October-November, 1980 period, it was greater in the following February-March period. The relative stem diameter growth was for the remainder of the months, except in March, 1982, greater than the control.

The seasonal growth of both *E.viminalis* and *E.melliodora* and the effect the various treatments had on that growth are further discussed in Chapter 5.

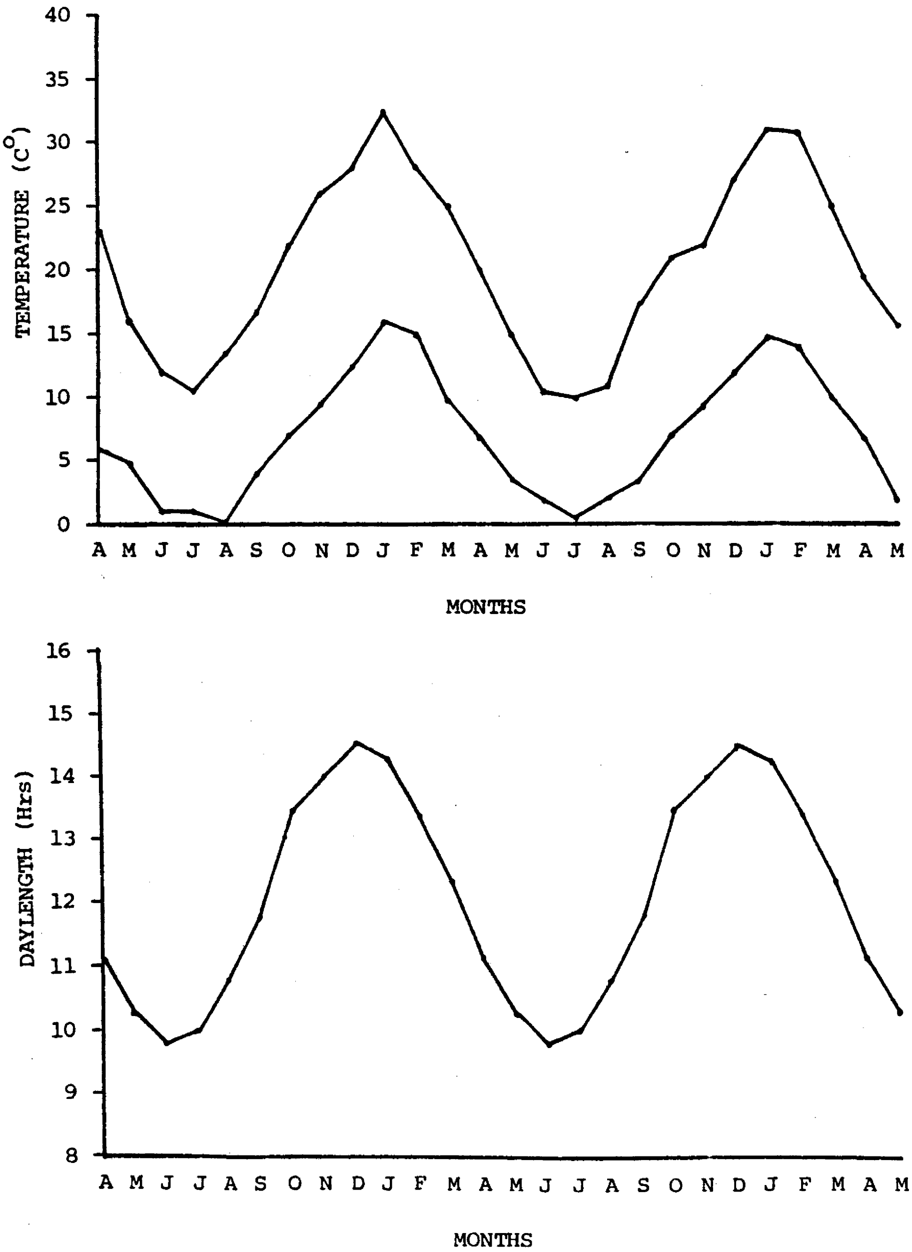
4.6 Meteorological Data and its Correlation to the Seasonal Height Growth of *E.viminalis* and *E.melliodora*:

4.6.1 Meteorological Data:

The monthly temperature, daylength, rainfall relative humidity and evaporation are recorded in Figs. 4.18-4.22 and the monthly wind is recorded in Table 4.4. The day length and evaporation figures were

FIG. 4.18: The average monthly minimum and maximum temperatures recorded at the experimental plantation from April, 1980 to May, 1982.

FIG. 4.19: The average monthly day length recorded in Canberra from April, 1980 to May, 1982. It represents the time from sunrise to sunset in relation to civil twilight.

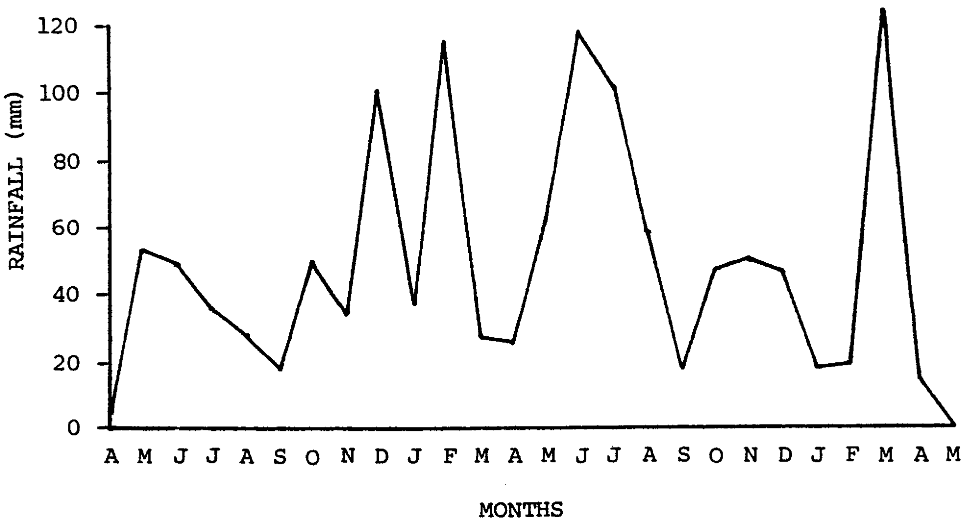


40
35
30
25
20
15
10
5
0
TEMPERATURE (C°)
A M J J A S O N D J F M A M J J A S O N D J F M A M
MONTHS
16
15
14
13
12
11
10
9
8
DAYLENGTH (Hrs)
A M J J A S O N D J F M A M J J A S O N D J F M A M
MONTHS

FIG. 4.20: The monthly rainfall measured in the experimental plantation from April, 1980 to May, 1982.

FIG. 4.21: The average monthly percentage relative humidity at 3.00p.m. recorded in the experimental plantation from April, 1980 to May, 1982.

FIG. 4.22: The average monthly evaporation recorded in Canberra from April, 1980 to May, 1982.


RAINFALL (mm)
0
20
40
60
80
100
120
A M J J A S O N D J F M A M J J A S O N D J F M A M
MONTHS


% RELATIVE HUMIDITY
0
10
20
30
40
50
60
A M J J A S O N D J F M A M J J A S O N D J F M A M
MONTHS


EVAPORATION (mm)
0
100
200
A M J J A S O N D J F M A M J J A S O N D J F M A M
MONTHS

obtained from the Bureau of Meteorology having been recorded in Canberra City.

TABLE 4.4

Monthly Wind Runs* (km/month)

Month	1981	1982
Jan	3501	3267
Feb	2624	2667
Mar	2582	2532
Apr	1911	1462
May	2144	2088
June	3008	
July	3030	
Aug	3614	
Sept	2952	
Oct	3175	
Nov	3206	
Dec	3893	

*As the first anemometer used stopped functioning in November, 1980 the wind runs are only those recorded with the second anemometer.

4.6.2 Correlation Between Meteorological Data and Height Growth:

To assess the relationship between the height growth of the eucalypts and the fluctuations in climatic conditions and to test its significance at population level,correlation tests were used (Parker, 1979).

The correlation of the height growth of both *E.viminalis* and *E.melliodora* with average maximum temperature, day length, rainfall, humidity and evaporation is given in Table 4.5. The temperature and day length was correlated with those trees sprayed and irrigated to reduce the effect of rainfall while the rainfall, humidity and evaporation was correlated with those trees sprayed but not irrigated to remove the influence of irrigation.

TABLE 4.5

Correlation of Height Growth with Environmental Variables

Variable	Correlation Co-efficient	
	E. viminalis	*E. melliodora*
Temperature (Average monthly maximum)	+0.46	+0.45
Day length	+0.58	+0.66
Rainfall	+0.04*	-0.09*
Humidity	-0.47	-0.49
Evaporation	+0.51	+0.47

*Not significant

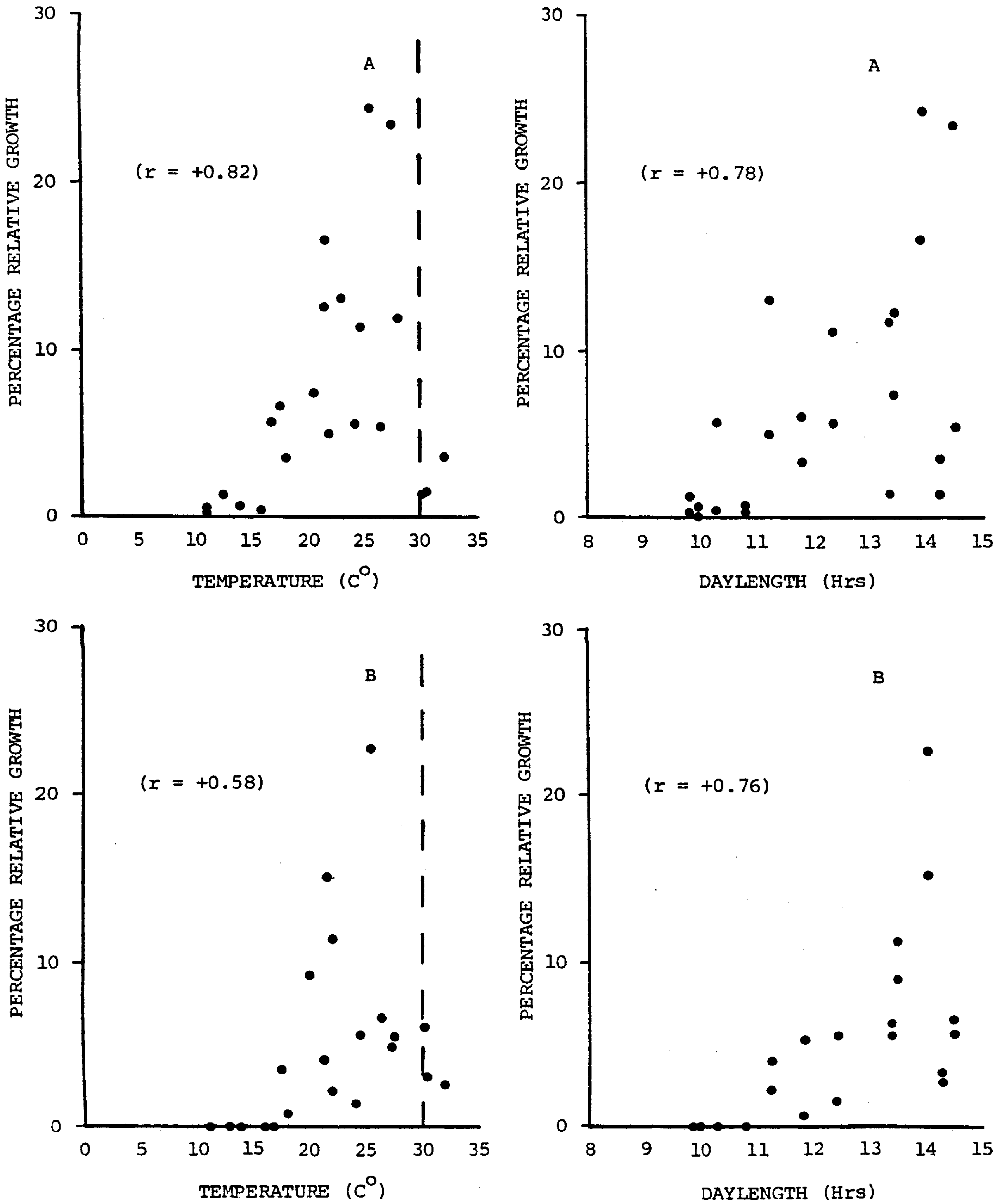
Of the environmental variables, day length provided the closest correlation with height growth whereas there was almost no correlation between height growth and rainfall. Both temperature and evaporation also correlated significantly with the height growth. Humidity had a negative correlation with decreased growth as humidity increased.

Because of the relation between day length and temperature, evaporation and humidity, the significant correlation of all the variables would be expected.

Temperature and day length are generally considered the most important in regard to seasonal plant growth.

At temperatures above 30°C, the height growth

FIG. 4.23: Correlation between the height growth of *E.viminalis* (A) and *E.melliodora* (B) and temperature and day length. The correlation coefficients are for temperatures below 30^{o}C and day lengths of the corresponding months.



30
20
10
0
A
(r = +0.82)
PERCENTAGE RELATIVE GROWTH
0 5 10 15 20 25 30 35
TEMPERATURE (C°)
A
(r = +0.78)
8 9 10 11 12 13 14 15
DAYLENGTH (Hrs)
B
(r = +0.58)
B
(r = +0.76)

of *E.viminalis* was noticeably suppressed, as was the height growth of the *E.melliodora* in the January of both years. If the height growth of the *E.viminalis* and *E.melliodora* is correlated with temperatures below 30^{o}C., the correlation is markedly improved, particularly for *E.viminalis* (see, Fig.4.23). The correlation with the day length of the corresponding months was also improved, but was less than that for temperature in the case of *E.viminalis*. For *E.melliodora*, however, the day length still correlated significantly more strongly than temperature.

The effect of the climatic variables is further discussed in Chapter 5.

4.7 Response to Water Stress by *E.viminalis* and *E.melliodora*:

4.7.1 Introduction:

The survey of the habitat preference of *E.viminalis* in the A.C.T. and surrounding districts showed the species to have a preference for moister areas whereas *E.melliodora* was found to inhabit the drier regions. This distribution of the two species and the greater reduction in January growth by the *E.viminalis* suggested a difference in the species' ability to tolerate conditions of low soil water content and high evaporative demand. To examine this the following experiment was conducted.

4.7.2 Experimental Method:

Twelve *E.viminalis* and twelve *E.melliodora* were planted at the Botany Department's Plant Culture Area of the Australian National University in March, 1981. They were planted in a single row of alternating species, as at the Cotter Plots in an east-west alignment.

All of the trees were trickle irrigated until three weeks prior to the experiment, from when half of the trees of each species were not irrigated. Those trees being irrigated were each given 10 litres per week.

The experiment was conducted on the 12 February, 1982 and the soil around those trees being irrigated was at field capacity.

4.7.3 Parameters Measured:

The experiment was conducted over the course of one day. During that day two parameters were measured; 1) total water potential, and 2) stomatal diffusive resistance. Also, leaves were collected for the later measurement of osmotic potential.

The total water potential was measured using the pressure chamber method (Scholander *et al.*, 1964). A young shoot was cut from each tree for each measurement just above the sixth leaf (or pair of leaves in the case of *E.viminalis*). The shoot was placed in a plastic bag before cutting, was cut and then placed into the pressure chamber while still in the plastic bag. The bag was used to reduce moisture loss from the shoot (Turner and Long, 1980).

The stomatal diffusive resistance was measured with a diffusion porometer (Jarvis, Rose and Begg, 1967). The leaf measured was the sixth leaf on the uncut shoot.

Immediately after the shoot was cut for the total water potential measurement the sixth leaf (or pair of leaves) was removed, placed in a small vial and then into dry ice. The samples were kept frozen until the osmotic potential measurements were made. The osmotic potential was measured using a thermocouple psychrometer (Spanner, 1951).

The measurements were made at 0900, 1200, 1500, 1700 and 1900 hours.

4.7.4 Results:

The maximum screen temperature recorded at the Plant Culture Area on the day was 36.1°C. at 1500 hours. The relative humidity at 0900 hours was 68% and at 1500 hours was 33%. The evaporation recorded for the day was 8.8mm.

In the three weeks prior to the experiment, when half of the trees were not being irrigated, the rainfall was 11.8mm. The evaporation for the same period was about 150mm, with 92mm in February.

The total water potentials, osmotic potentials and stomatal diffusive resistances of both species are given in Fig. 4.24. The calculated pressure potentials are given in Table 4.6.

FIG.4.24: The water potentials, osmotic potentials and stomatal diffusive resistances of both irrigated (•——•) and unirrigated (•- - -•) *E.viminalis* (A) and *E.melliodora* (B).

Least significant differences* for graphs:

	E.viminalis		*E.melliodora*	
	Irrigated	Unirrigated	Irrigated	Unirrigated
Water Potentials (kPa)	185	298	167	322
Osmotic Potentials (kPa)	392	358	309	408
Diffusive Resistance ($sec.cm^{-1}$)	4.5	8.9	1.2	4.3

*(P=0.05)

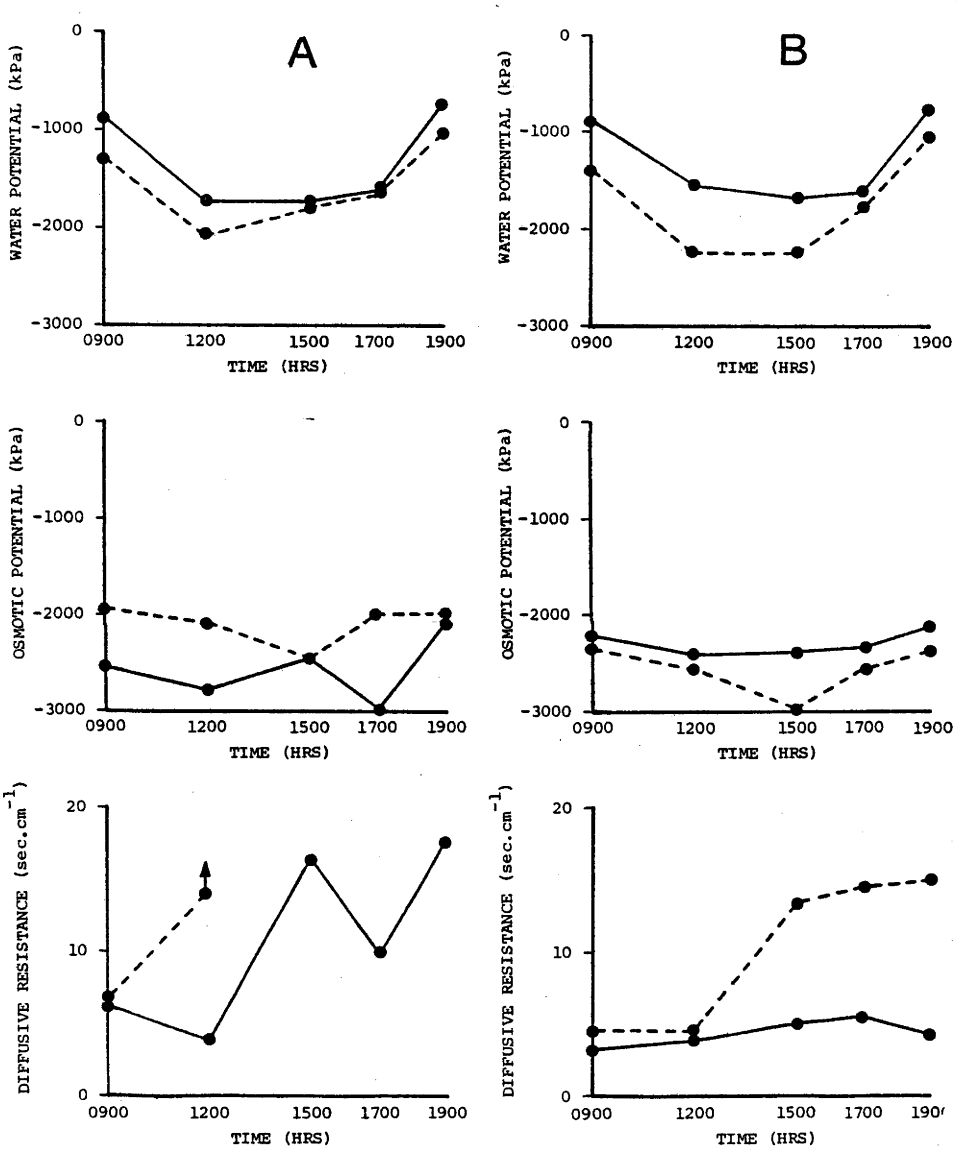

A
B
WATER POTENTIAL (kPa)
OSMOTIC POTENTIAL (kPa)
DIFFUSIVE RESISTANCE (sec.cm^{-1})
TIME (HRS)
0
-1000
-2000
-3000
0900
1200
1500
1700
1900
20
10

TABLE 4.6

Pressure Potentials (kPa)

	E.viminalis		*E.melliodora*	
Time (hrs.)	Irrigated	Unirrigated	Irrigated	Unirrigated
0900	1667	648	1337	966
1200	1056	50	866	371
1500	707	698	675	745
1700	1363	351	718	780
1900	1358	978	1317	1324

The water potential of all of the trees, whether irrigated or not, decreased between 0900 and 1200 hours and again increased between 1700 and 1900 hours. The two groups of trees not irrigated had the lowest water potentials with the unirrigated *E.melliodora* having the lowest.

The irrigated *E.melliodora* had the highest water potential throughout the day, except at 1900 hours.

The osmotic potentials of both species when not irrigated followed the same pattern during the day reaching their lowest level at 1700 hours. The unirrigated *E.melliodora* had the lowest osmotic potential. The least affected trees were the irrigated *E.melliodora*, whereas the irrigated *E.viminalis* decreased twice during the day, at 1200 and 1700 hours. The unirrigated *E.viminalis* had the highest osmotic potential throughout the day except at 1500 hours when exceeded by the irrigated *E.melliodora*.

The pressure potential of the unirrigated trees was the lowest with the unirrigated *E.viminalis* being close to wilting at 1200 hours. The pressure potentials of the irrigated trees were also reduced during the day with that of the *E.melliodora* being slightly lower than the *E.viminalis* at 1500 hours. The pressure potentials of all the trees, except the unirrigated *E.viminalis*, rose to over 1300 kPa at 1900 hours, with the irrigated *E.viminalis* having reached that level by 1700 hours.

The stomatal diffusive resistance followed a similar pattern to the osmotic potentials in the irrigated trees, particularly in the *E.viminalis*. The diffusive resistance of the unirrigated *E.viminalis* was out of the range of the instrument after 1200 hours, indicating complete or near complete stomatal closure. All the trees showed some increase in diffusive resistance after 1200 hours. This experiment is further discussed in Chapter 5.

4.8 The Effect of Day Length on Vegetative Growth:

4.8.1 Introduction:

The seasonal growth observed for both *E.viminalis* and *E.melliodora* in the first year showed a definite pattern of height growth with peaks in November and February. When the monthly percentage relative height growth was correlated with temperature and day length a strong correlation with day length was found for both species. To examine whether an optimum day length for height growth existed the following experiment was conducted.

4.8.2 *Eucalyptus* Species Used:

Four species of eucalypts were used for the experiment. These were *E.viminalis*, *E.melliodora*, *E.pauciflora* Sieb. ex Spreng. and *E.stellulata* Sieb. ex DC. The latter two were chosen because of their distribution. Similar to *E.viminalis*, neither species extends further north than 28°S. This distribution is particularly relevant if an optimum day length of about 14 hours exists, as the day length in areas north of 28°S does not reach 14 hours in any month of the year.

Also, *E.viminalis*, *E.pauciflora* and *E.stellulata* extend into areas which can have large temperature fluctuations in all months of the year and which are, at times, snow-covered during winter. However, the latter two species extend much further into the cold regions of Australia than does *E.viminalis*.

4.8.3 Experimental Method:

Of all the growing months the most height growth was recorded in November for both species. The average temperature regime for the month was about 24°C/day and 10°C/night. This temperature regime was used for all day lengths. The day lengths used were 12, 14 and 16 hours.

The experiment was conducted in three Morse and Evans cabinets (Morse and Evans, 1962) for three months from 30 October, 1981 to 29 January, 1982.

The eucalypts were three months old when the experiment was commenced. Six replicates of each eucalypt were used in each cabinet and the replicates were randomly arranged within the cabinets.

To ensure that the trees were all receiving the same amount of light energy in each cabinet, the trays were set at a height at which about 380μ einsteins $m^{-2}sec^{-1}$ was delivered to the centre of each tray.

After the plants had been placed in the cabinets the light and radiation levels were measured at plant canopy level in each cabinet. These measurements were:

Cabinet 1:	Light	-	22.3 klux
	Radiation	-	87 W/m^2
Cabinet 2:	Light	-	21.9 klux
	Radiation	-	88 W/m^2
Cabinet 3:	Light	-	22.5 klux
	Radiation	-	88 W/m^2

4.8.4 Results:

At the conclusion of the three months the plant shoots were harvested and dried at 70°C for 48 hours. The dried shoots were then weighed. The results are presented in Fig. 4.25.

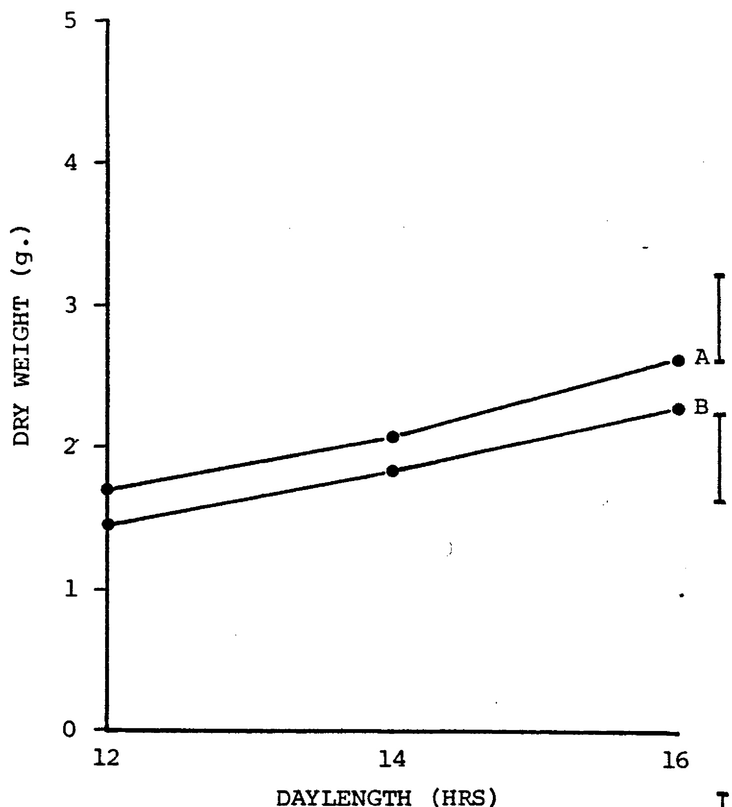
From the results of the experiment it appears that *E.viminalis* and *E.melliodora* do not have an optimum day length of 14 hours, but rather increase their growth when the day length is increased. The growth of the *E.pauciflora* and *E.stellulata* did not increase with the increase in day length from 14 to 16 hours which suggests a daylength response. This experiment is further discussed in Chapter 5.

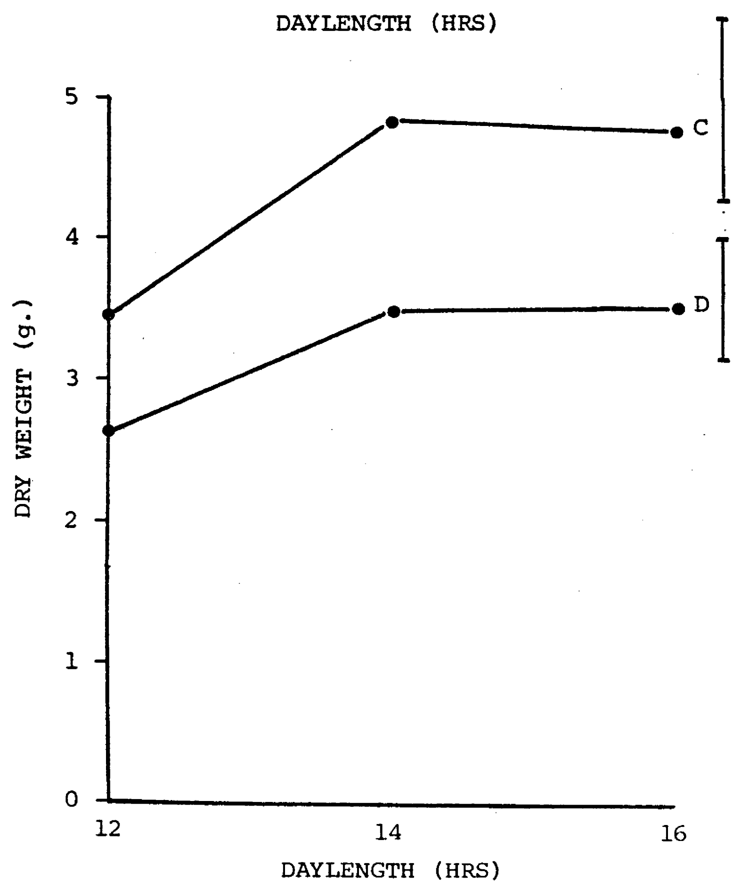
4.9 An Assessment of the Presence and Damage Caused by Insects on the Unsprayed *E.viminalis* and *E.melliodora*:

4.9.1 Introduction:

Insects can greatly influence the survival of any

FIG. 4.25: The dry weight of *E.melliodora* (A), *E.viminalis* (B), *E.pauciflora* (C), *E.stellulata* (D) shoots, grown at day lengths of 12, 14 and 16 hours and at a temperature of 24^{o}C/day and 10^{o}C/night. The LSD bars for A and B are $P = 0.05$ and for C and D are $P = 0.10$.


5
4
3
2
1
0
DRY WEIGHT (g.)
A
B
12
14
16
DAYLENGTH (HRS)


5
4
3
2
1
0
DRY WEIGHT (g.)
C
D
12
14
16
DAYLENGTH (HRS)

plant species. Turnbull and Pryor (1978) note that a range of insects can cause serious damage to *E.viminalis*, both in plantations and in its natural environment. However, the effect of insects on a species on a given site is not readily predictable and preliminary trials are necessary to establish whether a problem normally exists. Those trees in the experimental plantations that were not sprayed provided information on whether insect control was beneficial and also permitted an assessment of the insect species present on the two species during the growing season. The trees were examined on a monthly basis from August, 1981 to March, 1982.

4.9.2 Method:

The assessment was made in the middle of each month and was conducted early in the morning while most of the insects were still active on the trees. Each tree was inspected and the presence of any insects and insect damage was noted. Any insects that were not known were recorded and collected for identification at the CSIRO Division of Entomology.

4.9.3 Results:

The record of damage caused by particular insect families or genera is given in Tables 4.7 and 4.8.

A record of all the insect families and genera that were recorded on the trees and were identified as known pests or predators of those pests is given below.

A. Major Pests:

(i) Leaf-eating: Coleoptera - 'Beetles'

Chrysomelidae 'Chrysomelid Leaf Beetles'

Paropsis atomaria
Paropsisterna beata
Chrysophtharta sp
Edusella spinicellis

Curculionidae - 'Weevils'

Gonipterus scutellatus 'Eucalyptus snout beetle'

Scarabaeidae - 'Scarab Beetles'

Anaplognanthus viriditarsis 'Christmas Beetle'

Hymenoptera

Pergidae - 'Sawflies'

Perga affinis - 'Eucalyptus Saw-fly'

(ii) Sap-sucking: Hemiptera

Eurymelidae - 'Leaf-hoppers'

Eurymela distinta

Psyllidae - 'Lerp-insects'

Glycaspis sp
Spondyliaspis sp
Creiis sp

Eriococcidae - 'Scale-insects'

Eriococcus coriaceus 'Eucalyptus-scale'

B. Minor Pests:

(i) Leaf-eating: Lepidoptera - 'Moths and Butterflies'

Zygaenidae

Doratifera sp 'Cup Gum Moth'

Geometridae

Mnesampela privata 'Autumn Gum Moth'

Orthoptera - 'Grasshoppers'

Tettigoniidae

Torbia sp

Acrididae

(ii) Sap-sucking: Hemiptera

Eurymelidae - 'Leaf-hoppers'

Eurymeloides sp

Machaerotidae - 'Plant-bugs'

Chaetophyes compacta

Pentatomidae - 'Shield-bugs'

Poecilometis sp

Acanthosomatidae - 'Shield-bugs'

Anischys sp

(iii) Wood-boring:

Coleoptera - 'Beetles'

Buprestidae - 'Jewel Beetles'

Nascio vestusta

(iv) Stem Galls: Lepidoptera - 'Moths and Butterflies'

Tortricidae

(Although other stem galls were present, those caused by the above insect were the only ones recorded because of their obvious damaging effect).

(v) Leaf Galls: Leaf Galls on the leaves of main *E.melliodora* and also *E.viminalis* were recorded but not identified.

(vi) Stem Borers: Diptera - 'Flies'

Agromyzidae

C. <u>Predators</u>:

Coleoptera - 'Beetles'

Coccinellidae - 'Ladybirds'

Rhizobius sp
Coccinella sp
Harmonia sp

Cleridae - 'Clerids'

Trogodendron fasciculatum - 'Yellow-horned Clerid'

Cantharidae - 'Soldier Beetles'

Chauliognathus sp

Lycidae

Metriorrhynchus sp

Hemiptera

Pentatomidae - 'Shield Bugs'

Oechalia schellenbergia

Manotea - 'Praying Mantids'

Mantidae

Neuroptera - 'Lace-wings'

The numbers of insects present and the damage caused by them was greater on *E.viminalis* than on *E.melliodora* in all of the months recorded.

Of the insects present on the *E.viminalis* the most obvious damage done to both young shoots and older foliage was caused by the beetles and their larvae. This, in particular, included the chrysomelids, the eucalypt snout beetles (*Gonipterus*) and the Christmas beetles (*Anaplognanthus*). Other obviously damaging insects on the *E.viminalis* included the sawfly larvae

(*Perga*), the large leaf-hoppers (*Eurymela*) and the psyllids. The most effective predators were ladybirds (Coccinellidae) which, from the visual assessment, effectively controlled and actually reduced the eucalypt scale(*Eriococcus*). Those *E.viminalis* that were irrigated appear to have been more damaged by the beetles, particularly during November, and the unirrigated trees had bigger populations of the large leaf-hoppers, and showed more damage caused by them.

Of the insects that were on the *E.melliodora* only the fly larvae (Agromyzidae) caused any damage which affected the trees' growth. The *E.melliodora* did not appear to have been badly damaged by any of the other insects recorded.

The effect of the insects on the trees' seasonal growth will be further discussed in Chapter 5.

TABLE 4.7

Insects Present on Unsprayed, Irrigated *E.viminalis* and *E.Melliodora* from August, 1981 - March, 1982*

Insects	Aug.		Sept.		Oct.		Nov.		Dec.		Jan.		Feb.		Mar.	
	V[a]	M[b]	V	M	V	M	V	M	V	M	V	M	V	M	V	M
A. PESTS:																
Chrysomelidae			2		2		4	2	3	1	3	1		1	3	
Gonipterus			2		1		4		3		1	1	1		1	
Anaplognanthus											2		3			
Perga			2		3		4									
Eurymelidae	2		3		3		1		3		3		1		2	
Machaerotidae						1	1	1	1	1	1	1			2	
Psyllidae				1		1	2	1	4	3	3	1	3	1	3	1
Eriococcus	2				2		2		2		2					
Doratifera																
Tettigoniidae					1	1		1	1	1						
Acrididae													1	1		3
Pentatomidae											2		1			
Nascio													1			
Agromyzidae														2		3
Leaf Galls	1	1		1		1				1			1	2		
Stem Galls												2				
Mnesampela		2														
B. PREDATORS:																
Coccinellidae	1	1		1			2	1	2							
Trogodendron									2							
Mantidae																
Neuroptera					1		2		2						1	
Oechalia										1					1	

* Key to Scoring: a - *E.viminalis* b - *E.melliodora*

Pests: 1 - Present but no damage observed
2 - Present and causing damage to less than 25% of the foliage on some of the tress assessed
3 - Present and causing damage to less than 25% of the foliage on all of the trees assessed
4 - Present on all of the trees and causing damage to more than 25% of the foliage on at least half of the trees assessed

Predators:
1 - Present
2 - Predation of pests observed

TABLE 4.8

Insects Present on Unsprayed, Unirrigated *E.viminalis* and *E.melliodora* from August, 1981 - March, 1982*

Insects	Aug.		Sept.		Oct.		Nov.		Dec.		Jan.		Feb.		Mar.	
	V[a]	M[b]	V	M	V	M	V	M	V	M	V	M	V	M	V	M
A. Pests:																
Chrysomelidae			1		2		3	2	3	1	2	1	2			
Gonipterus					1		4				3		1		2	
Anaplognanthus											4					
Perga			2		2											
Eurymelidae	3	3	3		3		2		3		3		1	1	2	
Machaerotidae									1	1	1	1		1		2
Psyllidae				1		2	2	3	3	3	1	1	3	2	4	3
Eriococcus	2		2		2		1		3		1					
Doratifera												2				
Tettigoniidae											1					
Acrididae														1		
Nascio																
Agromyzidae																3
Mnesampela		2														
Geometridae						2						2				
Leaf Galls		1		1						1		1		1		
Stem Galls													1	1		2
B. PREDATORS:																
Coccinellidae	1				1	1	2		1		1					
Trogodendron																
Mantidae									1							
Neuroptera							1									
Oechalia											1				1	

* Key to scoring as for Table 4.7

CHAPTER FIVE

DISCUSSION

The results and observations of this study have shown obvious differences between the growth of *E.viminalis* and *E.melliodora*. These differences suggest several reasons for the poor performance of *E.viminalis* in urban plantations.

5.1 Differences in Growth Form and Growth Rate Between *E.viminalis* and *E.melliodora*:

As the form of woody plants is determined by the differential elongation of buds and branches, the expression of a particular growth habit is commonly associated with apical dominance (Zimmerman and Brown, 1971). In a woodland tree, such as *E.melliodora*, the lateral branches often grow as fast as the terminal shoot giving rise to a decurrent growth habit where the central stem eventually disappears from repeated forking to form a huge spreading crown. In forest species the main stem or leader outgrows the lateral branches below giving rise to a cone-shaped crown and a clearly defined central stem.

For a forest tree to retain its form it must maintain the fast growing dominant leader. This characteristic is useful when determining a young tree's potential form. Most of the *E.viminalis* in the experimental plantation had an obviously dominant leader and little branching.

The observed form of the young *E.viminalis* questions whether the Lake George population is one that naturally established under the woodland conditions or is rather the relict of an earlier forest population. Studies made on the vegetation history of the Lake George area suggests the latter (Singh, pers. comm.). Pollen from a group of forest eucalypt species including *E.fastigata* has been extracted from Lake George soil core samples dating up until recently. Not only does *E.fastigata* still occur within 30km of Lake George, but also commonly occurs with *E.viminalis*.

Possibly related to the species forest form, the growing tips on the *E.viminalis* are more resistant to unfavourable climatic conditions. This provides *E.viminalis* with two major advantages: the capability of continuing growth whenever conditions permit, and not having to regularly develop new buds which would probably result in loss of form. This applies to many eucalypt species, as the loss of one growing point can often result in several new shoots replacing it. Such a profusion of growing points does not change the form of a tree which is naturally decurrent.

The difference in growth rate between the two species also indicates a basic difference. When growing in a forest environment a eucalypt sapling has to maintain a rapid growth rate to successfully compete with other samplings. Such rapid growth is not required in an open woodland environment, as there is not the same competition for light. The *E.viminalis* used for this study exhibited the rapid growth of a forest species.

The ability for *E.viminalis* occurring in a woodland area to exhibit rapid growth was also shown in Victoria (Ladiges and Ashton, 1974).

Being a species only occurring in woodland areas, *E.melliodora* does not require rapid growth height. Instead, the species appears to use a greater percentage of its photosynthates to increase its stem diameter. This may be due to the species occurring in open areas and, being more prone to strong winds, requires a more robust trunk to avoid damage when the tree is small. A well-developed trunk is also important for support for the huge spreading crown when mature.

The stage of maturity reached by the two species by the end of this experiment also showed differences between the two species.

As with most eucalypt species, *E.viminalis* and *E.melliodora* both develop juvenile and adult foliage. Of the *E.viminalis* in the experimental plantation, most trees had adult foliage making up a significant proportion of their entire foliage by the end of the study. This applied to only a few *E.melliodora*. As the foliage on most eucalypts begins to change from juvenile to adult after about the 20th - 30th node, or at about 2m (Pryor, 1976), the fact that the height growth of the *E.viminalis* was much greater may explain the difference.

The *E.viminalis* also appeared to be more ontogenetically mature than the *E.melliodora*,with 19 *E.viminalis* having flower buds compared to only one

E.melliodora. As the flower buds were usually among the juvenile foliage it is likely that they were formed in the first year. This earlier maturity may also be related to *E.viminalis'* more rapid growth rate.

When examining the differences in growth habit and growth rate between the two species, *E.melliodora* was considered as the typical woodland tree, with any differences seen in *E.viminalis* being taken as deviations from that standard. To determine whether the differences were due to traits peculiar to *E.melliodora,* two other associated woodland species were examined. These were *E.blakelyi* and *E.albens,* both of which occur naturally with *E.melliodora.* Both *E.blakelyi* and *E.albens* show a decurrent form as saplings and mature trees. Also, the buds and young shoots of both species are excised during winter, continuing growth only after new shoots have developed in spring. Although there are taxonomic differences between the three species (Pryor and Johnson, 1971), the habitat common to all of them appears to have resulted in similar growth habits.

It seems, therefore, that for a species growing in a woodland, the characteristics of the Lake George *E.viminalis* are unusual. They are more like the characteristics of the forest population present at Lake George during earlier times of higher rainfall.

5.2 Seasonal Growth in *E.viminalis* and *E.melliodora*:

5.2.1 Seasonal Growth of Eucalypts in Australia:

Research into the seasonal growth of eucalypts has been limited and the localities in which the work has been done are widespread.

Two distinct seasonal height growth cycles have been described. The first shows maximum height growth in summer and virtually no growth in winter. This cycle appears to be restricted to areas with high annual rainfall and/or moderate maximum summer temperature. Recordings of this unimodal cycle are summarised in Table 5.1.

TABLE 5.1

Occurrence of *Eucalyptus* Showing Unimodal Growth Cycle

Eucalypt Species	Occurrence	Annual Rainfall (mm)	Summer Max Temperature (°C)	Reference
E.viminalis	Trentham (Vic.)	1040	28	Ladiges & Ashton (1974)
E.regnans	Maydena (Tas.)	1230	22	Cremer (1975)
E.regnans	Wallaby Ck. (Vic.)	1215	28	Ashton (1975)
E.marginata	Dwellingup (W.A.)	1310	29	Loneragan (1971)
E.obliqua - *E.radiata*	Kingslake West (Vic.)	1210	28	Specht & Brouwer (1975)

The second seasonal height growth cycle is bimodal. The growth is maximum in spring and autumn, with a mid-summer reduction and virtually no growth during winter, as was recorded in this study.

Porter (1978) recorded this seasonal growth cycle for *E.sideroxylon* growing in the Bendigo district where the conditions are similar to Canberra's, with relatively low annual rainfall (541mm) and an average maximum January temperature of 30°C. Specht and Brouwer (1975) also recorded the bimodal cycle for *E.acmenoides*, *E.siderophloia*, *E.intermedia* and *E.maculata* in Brisbane. Sprecht records the two periods of reduced growth as being January-February in summer and July-August in winter.

Porter's (1978) results are the most similar to those recorded in this study. This is to be expected because of the climatic similarities of the two areas. Also, *E.sideroxylon* and *E.melliodora* are closely related (Pryor and Johnson, 1971) and are both native to savanna woodlands. If the results of this study and those of Porter's study are typical, then the seasonal growth cycle of most savanna woodland trees in areas with similar climatic conditions to Bendigo and Canberra can be expected to be bimodal.

Research into the seasonal stem diameter growth of eucalypts has also been very limited. For *E.regnans* at Wallaby Creek, the maximum diameter growth occurred in November just prior to the main shoot extension in December. There was also some increase in diameter after the summer shoot growth (Ashton, 1975). Pawsey (1964) also recorded the stem diameter growth as preceding the height growth in *P.radiata*.

This suggests that both *Pinus* and *Eucalyptus* species use stored reserves to expand pre-determined tissues in the buds before shoot extension. As the stem diameter growth uses stored reserves, it may be considered to be following the last flush of shoot growth rather than preceding the next. This would explain the early stem diameter growth in September and October after the shoot growth in March and April in this study. The growth did not occur earlier as the intervening months were too cold to sustain any substantial growth.

From the information available on the seasonal growth of eucalypts in Australia, it appears that the height growth is the most affected by climatic conditions.

5.2.2 The Effect of Temperature and Photoperiod on the Seasonal Growth of *E.viminalis* and *E.melliodora*:

Temperature may determine both the onset and cessation of plant growth as well as the rate of growth during the vegetative period.

Research on the effect of temperature on eucalypts has concluded that temperature is the most important environmental factor for any cyclic or optimum growth (Scurfield, 1961;Ashton, 1975;Cremer, 1975;Paton, 1978 and 1980).

Optimum Growing Temperatures: The optimum growing temperatures that have been recorded for eucalypt species relevant to this study are summarised in Table 5.2.

TABLE 5.2

Optimum Growing Temperatures for Some *Eucalyptus* Species

Species	Optimum Temperature (°C) Day	Night	Reference
E.blakelyi) *E.polyanthemos*) *E.pauciflora*)	24-30	19-25	Scurfield (1961)
E.viminalis	24	19	Banks (1972)
E.pauciflora	24	19	Green (1969)
E.regnans	24	19	Cremer (1975)
E.viminalis	24	19	Paton (1980)

While the most frequently recorded optimum temperature regime is $24^{\circ}/19^{\circ}$C., variation was found in some studies. Paton (1980) found that *E.viminalis* seedlings of the Whipstick and Eden provenances grew equally well at 33°C day and 28°C night. Green (1969) found that by the 19th week, *E.pauciflora* seedlings were growing fastest at $15^{\circ}/10^{\circ}$C and $18^{\circ}/13^{\circ}$C. A decrease in optimum day temperature from 30°C to 21°C with age (size) was also reported by Eldridge (1969) for *E.regnans*.

The reduced growth of the control *E.viminalis* in December, 1981 and February, 1982 compared to the continued growth in December, 1980 and February 1981 may indicate the reduction in optimum day temperature as recorded by Eldridge (1969) and Green (1969).

The optimum temperature regime for both the control *E.melliodora* and *E.viminalis* recorded during this study was $24^{\circ}/10^{\circ}$C. These results agree with the optimum day temperature suggested by the above-mentioned researchers. However, the night temperature is 9°C below their suggested optimum. In the areas in which *E.viminalis* occurs naturally, including the New South Wales Northern Tablelands, such differences in day and night temperatures would be common.

Cremer (1975) states it is not known whether mature trees of *E.regnans* (and this also applies to *E.viminalis*) benefit from day/night temperature differentials. However, Kramer (1957) records that the best growth of loblolly pine (*Pinus taeda*) occurred when a large difference existed between day and night temperatures and that there was poor growth when the nights were as warm as the days. When low nocturnal temperatures are beneficial to a plant, it would appear that they reduce respiration to a relatively low level so that the photosynthate produced during the day is conserved. If this is true, then, within certain limits, the greater the disparity between day and night temperatures, the more efficient the temperature relations with reference to the energy economy of the plant.

Temperature and Monthly Height Growth: The influence of temperature upon the monthly height growth of eucalypts during different seasons has been observed in various field studies (Cremer, 1975; Ashton, 1975; Ladiges and Ashton, 1974; Specht and Brouwer, 1975; Porter, 1978).

The weekly height growth of *E.regnans* at Maydena (Tas.) showed close correlation with the weekly average maximum temperatures, increasing with rising temperature in the range of 13°-25°C and being nil or only slight below 13°C (Cremer, 1975). The active growth of *E.regnans* at Wallaby Creek began when the average monthly maximum temperature rose above 15°C (Ashton, 1975), and *E.viminalis* growing at Trentham (Vic.) showed a similar trend (Ladiges and Ashton, 1974). In those areas of high rainfall and moderate maximum monthly temperatures, the seasonal height growth is directly controlled by air temperature.

When considering trees with a bimodal growth cycle, the relationship is not as simple, as high temperatures in mid-summer appear to be inhibitory, possibly as a result of the associated water stress.

The study of *E.sideroxylon* near Bendigo (Porter, 1978), records no growth below an average monthly maximum temperature of 16-17^{o}C. Porter associates the reduced summer growth with January's average maximum temperature of 30^{o}C.

The height growth of *E.viminalis* in this study was found to be nil or only slight when the average maximum monthly temperature was below 15-16^{o}C., and was also greatly reduced by an average maximum monthly temperature above 30^{o}C. As for those trees growing in areas of high rainfall and moderate summer temperatures, the height growth of *E.viminalis* correlated strongly with temperatures below 30^{o}C.

The height growth of the *E.melliodora* did not appear to be correlated with temperature as closely as with day length, possibly because the threshold temperature at the cessation of growth as compared to the threshold temperature for the commencement of growth was different.

<u>Day Length and Monthly Height Growth</u>: The research by Scurfield (1961) and Paton (1978) constitutes the major work done on the photoperiodic response in *Eucalyptus*. Scurfield (1961) using day lengths of 8 and 18 hours found that there was significantly more growth at 18 hours

than at 8 hours after 75 days. Paton's (1978) experimental treatments consisted of three growing temperatures (15/10, 24/19 and 33/28°C) combined factorially with three photoperiods (8, 12 and 16 hours). The results showed a greater growth response to temperature than to photoperiod. Further experimentation by Paton (1980) led to his conclusion that the relative insensitivity of *Eucalyptus* to day length emphasises the importance of temperature to growth and excluded day length and the combined effects of both.

The field studies by Ashton (1975), Cremer (1975) and Specht and Brouwer (1975) also conclude that seasonal height growth involves temperature rather than photoperiodic responses.

Some evidence of photoperiodic response in eucalypts has been found but this has mainly concerned flowering. *E.globulus* subsp. *bicostata* which usually flowers in Canberra in January has never flowered in Ethiopia (10°N) in the twelve years since its planting (Pryor, 1982, pers. comm.). At such a low latitude the day length would never reach the presumably required day length of over 14 hours.

Although the correlation of the height growth of *E.viminalis* with day length was significant, it is likely that its significance results from the relation between day length and temperature.

The height growth of *E.melliodora* appears to be considerably more affected by day length than by average maximum monthly temperature. This was found in both years of the study.

The most notable feature about *E.melliodora's* reaction to Canberra's winter is its apparent dormancy. Vince-Prue (1975) notes that any dormancy is an adaptation to unfavourable environmental conditions to which the dormant organ is more resistant than the non-dormant one. If a plant is going to use avoidance as a resistance mechanism then the key to successful adaptation to a recurrent pattern of change is preparedness (Sweeney, 1969). Thus, as one would expect, it is not the coming of the inclement conditions (i.e. low temperatures) which trigger the reaction, but rather an earlier warning such as day length.

Kramer (1957) found that temperatures may be responsible for initiating the height growth of *P.taeda* but not for its cessation, as it stops before temperatures are low enough to hinder it. This was also the case for *E.melliodora* in this study.

Height growth for *E.melliodora*, in both years, started when the mean monthly temperature was around 11^{o}C., but it had already ceased in mid-autumn before temperatures had fallen below 11^{o}C. The day length had, however, fallen below 11 hours at the cessation of growth and risen to about 11 hours when it commenced again.

A possible photoperiodic response was also seen for *E.melliodora* in the case of long day lengths. During this study, the species shoot growth was depressed in

December, not increasing again until February. Although the temperatures in February were higher than in December in both years, the former showed an increase in shoot growth. For both November and February the day length is just below 14 hours. However, the day length experiment performed in this study showed no reduction in growth with an increase in day length. This suggests a response other than photoperiodic, but it was not identified in this study.

The experiment did suggest, however, an optimum day length of around 14 hours for *E.pauciflora* and *E.stellulata*. Both of these species naturally occur in areas where temperatures fluctuate greatly, which is particularly important during the growing season. Because of this, it is possible that optimum growth is better related to a consistent optimum day length than to an optimum temperature. As both species often occur in woodland areas, sometimes with high evaporative demands in mid-summer, it is also possible that November and February provide the most favourable growing conditions, particularly at higher altitudes where winter conditions can occur earlier.

Temperature Extremes: As both *E.viminalis* and *E.melliodora* respond similarly to increases in average monthly maximum temperatures from about 16°C to 25°C., their responses to temperature extremes are more important when considering the differences between the two species.

Temperature extremes, apart from limiting physiological processes, may cause the death of whole or part of a plant and either eliminate it from a particular niche or reduce its competitive vigour. Resistance to temperature extremes is conveniently divided into resistance to heat and cold.

As most of the plantations in Canberra are usually in what were either woodland or grassland areas, the incidence of frost in those plantations is always high. All of the plantations assessed which showed large losses of *E.viminalis* were in frosty sites.

The results of this study, however, show that the frost protection given to both species in the experimental plantation during the first winter had no significant effect on their growth. The young shoots of the *E.melliodora* still became dessicated and were excised by the end of May.

While no work on the response of *E.melliodora* to low temperatures under controlled conditions appears to have been carried out, Paton (1980) and Paton, Slattery and Willing (1979) have made a comprehensive study of *E.viminalis*.

Paton (1980) found that low temperatures (2°C) rapidly increased the frost resistance of *E.viminalis*, with two days' exposure at this temperature allowing leaf and stem tissue to withstand temperatures of -6.5°C., which otherwise would have been lethal. Lowering the hardening temperature to -6.5°C provided some protection against -14°C. Although this rapid hardening explains the absence of injury in *E.viminalis* as a result of low temperatures and associated frosts, the dehardening has also been observed to be rapid (Paton, 1973; Aston and Paton, 1973). This suggests that if night temperatures are moderate for a few days, then the trees would be susceptible to a sudden frost. However, studies by Paton, Slattery and Willing (1979) showed that root temperatures of 0.5-1.0^{o}C effectively delay the dehardening of warm shoots.

Although the *E.melliodora* was not killed by the low temperatures recorded during this study, and though it does grow naturally in the Canberra region, it does not tolerate the winter conditions. The means of resistance appears to be avoidance as indicated by the excision of young buds and shoots.

In much of the research carried out on the effect of high temperature extremes on plants, temperatures have been over 40^{o}C (Bannister, 1976). Because the average maximum monthly temperatures causing growth reduction in Canberra are around 30^{o}C (though daily maximum temperatures can get to 40^{o}C) it is more likely that the growth is reduced as a result of adverse water relations rather than actual tissue damage caused by high temperatures. However, the fact that *E.melliodora* was able to increase its growth when the average maximum monthly temperature was over 30^{o}C suggests that the species is better adapted to the conditions created by high temperatures than is *E.viminalis*.

As the stem diameter growth appears to be closely related to height growth periods it is likely that the effect on stem diameter by extreme temperatures, unless they cause water stress, is as a result of its effect on height growth.

From this study, and from experimentation done by other researchers, the following conclusions as regard the effect of temperature and day length upon *E.viminalis* and *E.melliodora* can be made:

1. The height growth of *E.viminalis* was closely related to temperatures under 30°C., whereas *E.melliodora's* growth was possibly more closely controlled by day length.

2. Although the optimum growing temperature regime for *E.viminalis* was about 24/10°C for both years of the study, it was able to continue rapid growth under a higher temperature regime in the first year but not the second. This suggests a reduction in the optimum growing temperature with age. The optimum growing temperature regime for *E.melliodora* was also 24/10°C.

3. The average monthly temperature which determined the near cessation and then recommencement of growth before and after winter for *E.viminalis* was about 11°C. The average monthly temperature which initiated growth for *E.melliodora* after winter was also about 11°C. However, the growth had ceased before the temperature had fallen below 11°C before winter.

4. *E.viminalis* was able to tolerate minimum temperatures

of down to -6°C without any observable damage and to put on shoot growth when conditions permitted. *E.melliodora* did not tolerate the low temperatures and did not put on any growth during winter. However, *E.melliodora* was able to continue growing at average maximum monthly temperatures of up to 30°C., whereas the growth of *E.viminalis* was greatly reduced.

5. *E.viminalis* does not appear to be affected by day length, whereas *E.melliodora* appears to have a critical minimum day length.

6. The fact that the provision of frost covers did not affect the height growth of *E.melliodora* suggests that the growth had already stopped, or at least greatly slowed, before the first substantial frosts occurred.

7. Neither *E.viminalis* nor *E.melliodora* have a critical maximum day length up to 16 hours.

5.2.3 The Effect of Rainfall and Soil Moisture on the Growth of *E.viminalis* and *E.melliodora*:

The lack of correlation between rainfall and height growth seen in this study was also found with *E.regnans* (Cremer, 1975). Because of this the importance of rainfall is mainly concerned with the level of soil moisture as maintained by rainfall. Generally, the effect of rainfall when seen as an influence on the success or failure of a tree species in a relatively low rainfall area such as Canberra, concerns insufficient rainfall during periods of high evaporation.

<u>Effect of Irrigation</u>: The principle aim of irrigation is to replace moisture lost from the soil, to increase the growth and/or to ensure continued growth during periods when the rainfall is insufficient. By irrigating the trees, particularly during periods when both evaporation and transpiration rates are high (i.e. Dec. - Feb.), water stress can possibly be reduced and so growth loss minimised.

Although the results suggested that the aim of irrigation to improve tree growth was not achieved, the growth of the irrigated trees did continue during the 1981-82 summer when the monthly rainfall was considerably below average. The continuation of growth during the second summer suggests that over a longer period than the two years of the study, trees that are irrigated would become significantly larger. However, as those *E.viminalis* that were not irrigated grew as successfully as those irrigated and as the rainfall for the first year of the study was below average, the possibility of 'drought-hardening' can be suggested.

The concept of 'drought-hardening' has been proposed by Clemens and Jones (1978). Experimenting with *E.robusta*, some of the trees were conditioned by only watering them when they were obviously wilted. When control trees which had received daily watering were also dried down to wilting point, it was found that the conditioned plants transpired more slowly and did not wilt until 2-3 days after the control plants. From measurements of stomatal diffusive resistance, Clemens and Jones did not attribute the reduced water loss to stomatal control, but rather to lowered hydraulic conductivity of the root-stem system. If the same lowering in the root-stem conductivity occurred in those trees in the experimental plantation that were not irrigated, giving them some drought resistance, then this may answer their equally successful growth as those trees that were irrigated.

Response to Water Stress: While the height growth of the *E.viminalis* was significantly greater than the *E.melliodora* over the two year study, its relative growth during periods of high temperature and evaporation demand was significantly less. This is most likely the result of varying responses to water stress.

Pryor (1976) states that eucalypts, most of the time, do not economise their use of water but develop wide ranging root systems. Transpiration rates remain high even though the water supply from the soil is dwindling and it is only when severe wilting occurs that there is stomatal closure to inhibit water loss. *Eucalyptus calophylla* has been found to have closed stomata during the hottest part of the day while *E.marginata* continues to transpire even though wilting has ensued (Greive, 1956). Doley (1967) concluded that the latter relied on a deep, extensive root system. Similarly, Sinclair (1980) concluded that *E.fasciculosa* continues to transpire even in mid-summer when *E.obliqua* has closed its stomata as a result of a well-developed root system. Ladiges (1974;1976), however, when comparing the drought tolerance of *E.viminalis* of various Victorian provenances, suggested that for those *E.viminalis* from areas of low rainfall, the genetic differences may be related to the ability of the cytoplasm to tolerate desiccation rather than to more efficient means of restricting water loss. This may also apply to the *E.fasciculosa* and to *E.sideroxylon* when compared to *E.camaldulensis* (Quraishi and Kramer, 1970).

The results of the water stress experiment in this study showed that the irrigated *E.melliodora* continued to transpire and presumably photosynthesize even during the hottest part of the day. The irrigated *E.viminalis* was much more affected by the conditions, closing its stomata more than the unirrigated *E.melliodora*. This strongly suggests that *E.melliodora* is more able to continue to transpire and grow under moderate water stress than the Lake George *E.viminalis*.

When considering *E.melliodora's* response to the hottest part of the day, the low stomatal resistance may be of an advantage in an open, drier habitat such as a savanna woodland. In an environment where the maximum rate of photosynthesis is likely to be limited by the supply of carbon dioxide rather than by light intensity, a species such as *E.melliodora* may forego a degree of stomatal protection from desiccation for the sake of continued assimilation. The decreased stomatal resistance also results in a better coupling of leaf and air temperatures and reduces the chance of thermal damage (Levitt, 1972).

The difference between the *E.melliodora* and *E.viminalis* was emphasised by the stomatal reaction of those *E.viminalis* that were not irrigated. The most common ecological interpretation of stomatal closure is that it affords the plant protection from excessive water loss and consequently rapid and effective closure is a response against drought.

Theoretically, partially closed stomata are more resistant to water loss than they are to carbon dioxide uptake (Bannister, 1976). However, when complete closure occurs, CO_2 uptake ceases although water may still be lost through the cuticle. The partial closure of the stomata of the unirrigated *E.melliodora* may be related to this factor.

While the closure of the stomata in the case of the unirrigated *E.viminalis* may have been an adaptation against drought, it may have also been caused by overheating in the extremely hot conditions. The slump in the photosynthetic rate of *Zea mays* corresponding to the hottest period of the day is a consequence of the leaf overheating - increasing the respiratory CO_2 output and thus raising the substomatal CO_2 concentration to induce stomatal closure or increasing the leaf water deficit accentuating the stomatal closure (Gates, 1965).

There is also evidence that water stress greatly increases the sensitivity of the stomata to carbon dioxide (Heath and Mansfield, 1962).

Unlike those trees that were not irrigated, the stomatal closure of the irrigated *E.viminalis* may have been influenced by the low humidity rather than by the high temperature. Research on various plant species has shown that temperatures of 25-40°C have caused the stomata to open if soil moisture is not limiting (Schulze *et al.*, 1973; Stålfelt, 1962). It was when low humidity was experienced that this behaviour was reversed. Drake *et al.*, (1970) suggests that in a hot, dry area, stomatal opening in response to increased temperature, when the plants are not water stressed, would result in increased transpirational cooling. This would prevent overheating of the photosynthetic organs and lower leaf temperatures to a range more favourable for net photosynthesis. The irrigated *E.melliodora* appear to have taken this advantage of open stomata.

Although the total water potential (Ψ) of all the trees whether irrigated or not was adjusted during the day, the changes in ψ had little effect on the daily course of stomatal resistance (r_s). The peak of CO_2 uptake was reached when ψ had already reached its lowest values, as was found by Schulze *et al.*, (1975).

Of the components of ψ, the pressure potential (P) is thought to be the most important, directly affecting crucial physiological responses, and, in particular, growth (Hsaio *et al.*, 1976). The pressure potential, i.e. the difference between the measured ψ and osmotic potential (π), is usually positive. Wilting occurs when P=0 (Lange *et al.*, 1976). The stomata are thought to work in conjunction with solute regulation to maintain a positive P in the leaf rather than acting independently to maintain an apparently arbitrary level of ψ (Cowan, 1977; Davies *et al.*, 1981). The solution regulation (or osmoregulation) may result from either an increased uptake of mineral salts from the soil or from increased production of solutes in the plant.

In the case of the unirrigated *E.viminalis*, stomatal closure occurred when the pressure potential was low (P = 50kPa) and the plant was close to wilting. This closure resulted in an increase in P and presumably an associated increase in cell turgor. This response was also observed for the unirrigated *E.melliodora* but at a greater P value.

The turgor of both the irrigated *E.viminalis* and *E.melliodora* also fell. This was also probably the result of water loss. However, although the r_s of both the irrigated *E.viminalis* and the unirrigated *E.melliodora* was reduced to similar levels by 1500 hours, the *E.viminalis* did not increase or maintain the P . This is perhaps a result of the *E.melliodora* displaying osmoregulation. The result of increased π was illustrated by the rapid increase in P seen in the irrigated *E.viminalis* when the r_s was reduced, which possibly increased photosynthesis and solute production.

Any reduction in stem diameter growth during mid-winter or mid-summer may have been the result of water stress. However, as water stress can cause a diurnal fluctuation in stem diameter (Worrall, 1966), it is difficult to separate short-term stem shrinkage and actual reductions in growth.

From the results recorded at the experimental plot and in the water stress experiment, the following conclusions as regard the effect of rainfall and soil moisture on *E.viminalis* and *E.melliodora* can be made:

1. Neither *E.viminalis* nor *E.melliodora* showed any significant correlation between rainfall and height or stem diameter growth.

2. After an initial establishment period neither the height nor stem diameter growth of the *E.viminalis* and *E.melliodora* was significantly reduced when the trees were not irrigated.

3. As with other eucalypt species growing in areas of lower rainfall,*E.melliodora* continues to transpire during periods of high temperature,although there is some stomatal closure under conditions of moderate water stress.

4. When placed under moderate water stress *E.viminalis* is unable to maintain cell turgor without complete (or almost complete) stomatal closure after reaching near wilting point. This presumably results in both reduced

photosynthesis and reduced growth.

5. Whereas *E.melliodora* is able to return to a similar pressure potential, whether water stressed or not at sunset, *E.viminalis* is not. This is possibly explained by osmoregulation in the former.

5.2.4 The Effect of Wind on the Seasonal Growth of *E.viminalis* and *E.melliodora:*

Of the climatic factors assessed for their effect on the seasonal shoot growth of *E.viminalis* in this study, wind appears to have had the least effect. It seems to have mainly affected the shoot growth of *E.melliodora* in late autumn and particularly in early spring.

This effect on *E.melliodora* principally involved the excision of young shoots when either the growth was very slow or had stopped. Although no research was found to have been done on the effect of the wind on *E.viminalis* or *E.melliodora*, other research is applicable.

As wind removes the boundary layer of humid air from around a leaf's surface, so transpiration is increased. If a plant is not actively growing and replacing that lost moisture, the young leaves and shoots become desiccated (Bannister, 1976). In the case of the wind-protected *E.melliodora* in late autumn, this desiccation was found to take longer as the direct influence of the wind had been lessened. Also, and perhaps more importantly, the young shoots initiated in early spring grew earlier and faster on the protected trees. The increased relative stem diameter growth of the *E.melliodora* may have been related to the trees' greater height growth as much of the increased stem diameter growth also occurred in the late autumn and early spring period.

From the information recorded at the experimental plots the following conclusions as regard the effect of wind upon *E.viminalis* and *E.melliodora* can be made:

1. The shoot growth of *E.viminalis* was not affected by wind, however, wind protection did result in an increase in the relative height growth of *E.melliodora* in early spring.

2. Neither species showed any wind effect during the summer period when transpirational rates were already high.

5.2.5 <u>The Effect of Insects on the Seasonal Growth of *E.viminalis* and *E.melliodora*</u>:

The amount and time of damage done to a eucalypt by insects can greatly affect its survival. Under normal conditions and provided that the host has sufficient reserve for its own metabolic needs, ample food is available for insects. When an excessive build-up of an insect population occurs, the food resource can be exhausted. Also, if the tree is growing poorly, an average-sized insect population may again deplete the food resource. In the case of *E.viminalis*, the latter has quite likely occurred in many Canberra plantations.

Basically, the number and diversity of insects,in particular the more destructive insects, that were found on the *E.viminalis* was greater than on the *E.melliodora*.

However, the seasonal fluctuations that occur in insect populations are tied to both climatic conditions and food supplies and their numbers and the damage they cause varies from year to year. It is, therefore, not possible to assume that the insect populations present (or absent) will be the same for every year, but a record of one year can be used as a guide to a tree species' susceptibility.

In the period from August to October the most damage on both the irrigated and unirrigated *E.viminalis* was caused by the leaf-hopper *Eurymela distincta*. Neither this insect nor other leaf-hoppers are noted as being damaging in forests (Carne and Taylor, 1978), but the effect on the *E.viminalis* in the experimental plantation was significant. Smaller stems often broke off at the place where they had been feeding and it is likely that the damage they caused was important in increasing the stem diameter/height ratio. The damage caused by the Eurymelidae was slightly greater on the unirrigated trees but whether it was significant is difficult to determine,although it may have been related to reduced sap flow.

The eucalypt scale (*Eriococcus coriaceus*) has been recorded causing obvious damage to young *E.viminalis* (Carne and Taylor, 1978) but the scale recorded in the experimental plantation did not become a significant problem. This was most likely due to the presence of the predatory ladybird beetles (Coccinellidae) such as the *Rhizobius ventralis* which was particularly successful in New Zealand (Dumbleton, 1941).

The only obvious spring damage on the *E.melliodora* had been caused by the gum-leaf skeletoniser *Mnesampla privata*. Nevertheless, the damage was not extensive.

By October the adults of both the chrysomelids and eucalypt snout beetles (*Gonipterus scutellatus*) were present on *E.viminalis*.

The former is well recognised as a constant destructive force in Australian eucalypt forests, with beetles of the genera *Paropsis* and *Chrysophtharta* being the most important. As adults live for several weeks and females lay a succession of egg batches, all stages of the insect commonly co-exist during the summer months (Carne, 1966). As would be expected, the chrysomelid population was at its largest when the trees were producing the most young growth. The heaviest damage was on the irrigated trees and was most obvious on the rapidly growing young shoots. As both the adults and larvae are leaf-eaters there was damage caused by chrysomelids on the trees in all months except February.

Damage caused on eucalypts by the eucalypt snout beetle is thought to be worse outside of Australia than in native forests (Penfold and Willis, 1961). As with the chrysomelids, both the adults and larvae feed on and destroy leafy shoots in spring and summer. Although the larvae of this beetle was seen to do considerable damage to the *E.viminalis* in this study, Tooke (1955) records *E.viminalis* in South Africa as being one of the few species which did not suffer severe damage. However, it is listed as a favoured food source of the beetle in New Zealand (Penfold and Willis, 1961). Unlike the chrysomelid beetles, the eucalypt snout beetle caused an equal amount of damage to both the irrigated and unirrigated trees.

The sawfly (*Perga affinis)* larvae which was also feeding on the *E.viminalis* is a very well-known defoliator in Canberra. During October and November they are most obvious, often resting in large colonies around the stems of eucalypts during the day (Carne, 1962). Because they reach maturity by spring the damage they cause is limited to that period. However, because of the size of the larvae they can cause a large amount of damage in a short time. Like the chrysomelids, the sawfly appear to have a preference for the irrigated trees causing damage on them in November, 1981 while not being present on the unirrigated trees.

The apparent preference for the irrigated trees by both the chrysomelids and the sawfly larvae probably explains the reduced shoot growth of the irrigated *E.viminalis* in November as compared to the unirrigated trees.

The December psyllid infestations on the *E.viminalis* may explain why the growth of the unirrigated trees was less than those irrigated. Even though soil moisture levels were not limiting in that month large numbers of the insects can reduce the trees photosynthetic capacity which results in a decrease in growth (Carne and Taylor, 1978). Damage done by the psyllids at any time on the *E.melliodora* was only slight.

The Christmas beetle (*Anaplognanthus viriditarsis*) is another well-known eucalypt pest in Canberra. As the larvae live on grass roots the beetle is usually restricted to savanna woodland areas with trees such as *E.blakelyi* being a major food source. However, in earlier studies, *E.viminalis* has also been identified as a popular food source for Christmas beetles (Hughes, 1974). Although the damage done in the experimental plantation was obvious it was probably not as severe as that caused by the chrysomelids and eucalypt snout beetles. This is because the trees were only growing slowly and so the damage was on the older foliage.

The only other pest that had an obvious effect on the trees was fly larvae (Agromyzidae), on the *E.melliodora*. The fly is known to lay eggs in the young stems of eucalypts and the larvae cause the wilting and collapse of the shoots (Carne and Taylor, 1978). The result on a number of the trees was the loss of several young growing shoots up to 100mm in length. However, as this damage was only recorded at the end of the growing season its effect on the total year's growth was probably quite small.

Effect of Spraying for Insects: The aim of spraying is to reduce the destructive insect populations when the trees are putting on the most growth.

The measurements recorded suggest that the average height and stem diameter of the unsprayed *E.viminalis* was not significantly affected in its first two years of growth. Nevertheless, the change in the stem diameter/height ratio indicates a possible decline on the tree's future growth. This is supported by the information obtained from *E.viminalis* planted in City Parks' Belconnen Arboretum. In 1974 the *E.viminalis* at the arboretum had an average height of 4m (King,1982, unpubl. data). In 1982 the average height was still only 4.08m and all of the trees' crowns were flat topped (see, Fig. 5.1). The stem diameter/height ratio of the *E.viminalis* measured was 0.056. From this it is possible to suggest that while the stem diameters were continuing to increase, insect damage had stopped any further height growth. The continued grazing by insects appears to have been the cause of the loss of vigour and the eventual demise of most of the trees.

The same insect-initiated decline does not appear to have affected the *E.melliodora* either in the experimental plot or in the Belconnen arboretum.

From the information recorded at the experimental plots the following conclusions can be made as regard the effect of insect attack upon *E.viminalis* and *E.melliodora*:

1. *E.viminalis* appears to be considerably more damaged by insects than is *E.melliodora* and by a greater variety

FIG. 5.1: The complete loss of apical dominance in *E.viminalis* as a result of insect attack.

of insects.

2. The leaf-hoppers, *Eurymela distincta*, caused the earliest damage on *E.viminalis* after winter, often removing entire new shoots. They also appeared to have a preference for the unirrigated trees.

3. The most damage on *E.viminalis* occurred in November and was caused by the leaf-eating insects: chrysomelid beetles and their larvae, eucalypt snout beetles and their larvae, and sawfly larvae.

4. The chrysomelid beetles and their larvae and the sawfly larvae appeared to have a preference for the irrigated trees. This resulted in less growth for November compared to the unirrigated trees.

5. During the period of reduced growth during January *E.viminalis* is further damaged by Christmas beetles.

6. Both *E.viminalis* and *E.melliodora* suffer damage from psyllids, particularly in December and March.

5.3 The Effect of Establishment on the Growth of *E.viminalis* and *E.melliodora*.

Although a probable reason for the final demise of many *E.viminalis* can be seen as continued insect attack, the growth of the unsprayed trees in the experimental plantation still far outstripped that of even five year old plantation trees. This suggests that there is a further reason for *E.viminalis'* poor performance in those plantations.

'Establishment' in this study has referred to a three month period after planting during which the trees are regularly irrigated and sprayed for insects.

The success of a plant species' establishment in the seedling stage in the natural environment usually decides that species' long-term survival. The seedling is not only dependent on favourable climatic conditions but is also often competing with other plants of the same and different species. These other plants are competing for moisture, nutrients, and light.

In the savanna woodland the main plant group competing with the young eucalypts is the grasses which have the capacity for fast growth so as to take advantage of the prevailing conditions.

As the basins around the trees in the experimental plantation were always kept weed-free, the effect of weed competition could not be assessed. However, research was carried out by City Parks at the Cotter Plots to determine the value of using pre-emergent weedicides. The plant species used in the study included *E.viminalis*. They were planted in November, 1979 and their heights were measured after 12 months' growth (Clark, 1982). Of the treatments, one involved weeding by hand or chip-hoes (as in the experimental plantation) and the other involved no weed control after planting.

The average heights of the *E.viminalis* after 12 months were 1.73m for those trees in the hand-weeded plots and 1.44m for those trees in unweeded plots (Clark, 1982). This represents a significant height growth reduction of 20%, and gives some indication of the effect of weed competition.

The procedure of establishment ensures that a plant has enough water to permit the roots to spread from the original root ball. From the lack of growth by the unestablished *E.viminalis* in the months between October, 1981 and December, 1982, the plants had presumably not spread their roots sufficiently to maintain a water supply during those months of high temperatures and evaporative demand. This poor root development was probably the result of both low soil moisture levels and low temperatures. For the first two months after planting (March and April) when temperatures were high enough to promote growth, the rainfall was less than half the average. When the rainfall did increase in June the temperatures were too low to promote any substantial growth.

The November growth of the *E.melliodora* suggests that it was better able to continue growing under conditions of water stress. This probably aided the *E.melliodora* in two ways. Not only did it allow the continued growth in November but also possibly allowed the trees to become better established in March and April, 1981.

The experiment to determine the value of pre-emergent weedicides also provided information concerning the effect of not establishing *E.viminalis* during its early growth. The irrigation of the trees in the weedicide study increased the rainfall for the first three months by only 60mm and would not have greatly affected soil moisture levels. There is little difference between their average height (1.73m) and the average height of the unestablished trees in the experimental plantation (1.66m). This is particularly important as it suggests that the lack of establishment has a similar effect whether the trees are planted in early or late summer. It also supports the validity of comparing the first year's growth of those trees planted in 1981 with the first year's growth of those trees planted in 1980.

The effect of not establishing the *E.viminalis* for a three month period after planting was to significantly reduce the height and stem diameter growth for the first year at least. This initial reduction in growth combined with insect attack is most likely causing the demise of *E.viminalis* in the Canberra area in forward plantings. It would appear that if the trees are not properly established then they are at a definite disadvantage.

5.4 Effect of Mulching:

The aim of mulching trees is two-fold: to reduce the loss of moisture from the soil by evaporation and to suppress weed growth. As the basins in this study were weeded regularly, the second aim was not important for this study, but some observations were made.

In those basins that were mulched an increase in the soil's acidity was indicated by the common occurrence of the weed, *Rumex acetosella* or Sorrell (Burbidge and Gray, 1970). The weed was both vigorous and persistent and was not present in the basins of those trees not mulched. Although the *R.acetosella* was in the mulched basins, there were few grass weeds (*Digitaria sanguinalis*, *Eragrostis* sp. and occasionally *Paspalum dilatatum*), which were common in the unmulched basins. From these observations the problem of weed competition may still exist around mulched trees.

The necessity of using organic mulch for effective soil moisture retention has also been questioned, particularly in the case of weed-free basins. In a weed-free situation it can be argued that a surface layer of dry soil is as effective in reducing further evaporation of water from lower soil layers, as is a layer of mulch.

For comparison random soil samples were collected from the basins of both mulched and unmulched trees in the unirrigated plots. As evaporation occurs mostly from the top 200mm of soil (Daubenmire, 1959), the soil samples were taken to a depth of 150mm and the moisture content determined. The results are given in Table 5.3.

TABLE 5.3

Comparison of Soil Moisture Content

Depth (mm)	% Moisture Content Mulched	Unmulched
0-50	6.1	3.63
50-100	6.21	4.44
100-150	7.35	5.54

The moisture levels recorded showed that the mulch is effective in maintaining higher moisture levels, thus reducing the loss of water in the top 150mm of soil.

Despite the apparently more effective retention of soil moisture, the results recorded over the two year study show no significant difference in the total height or stem diameter growth between those trees mulched or unmulched, whether irrigated or not. This applied for both the *E.viminalis* and the *E.melliodora*. However, the significantly increased relative growth of those *E.melliodora* that were mulched and irrigated suggests that under continued drought conditions the total growth of *E.melliodora* at least may benefit significantly from the combination of mulching and irrigation.

5.5 The Effect of Seed Provenance Selection on the Success of Planted *E.viminalis* in Canberra.

As was noted in the Introduction, the *E.viminalis* in those plantations planted after 1970 had been the least successful.

The main *E.viminalis* seed provenance that has been used for Canberra's plantations was changed in the early 1970's. Before this time seed from trees west of Canberra in forest areas was used. After about 1972 seed from trees in the area on the western shore of Lake George was used. The reason for this change is likely to have been related to the similarity between the woodlands of Canberra and the Lake George area. Also, much of the planted forest provenance *E.viminalis* had suffered some degree of defoliation.

A good comparison between the growth of the forest and woodland provenance trees is provided by a landscape planting east of Lake Ginninderra, and is shown in Fig. 5.2. Whereas most of the forest provenance *E.viminalis* have retained apical dominance, all of the trees of the Lake George provenance had rounded crowns with no apical dominance. From this example it would appear that the forest provenances are likely to be much more successful. Further evidence supports this conclusion.

Two provenances (forest and woodland) of *E.viminalis* were planted at the Cotter Plots around 1950. Not only did the trees of the forest provenance have a better survival rate than the woodland trees (81% and 64%, respectively), but they also grew to nearly twice the height (15m and 8m, respectively) (Cremer, 1969).

A series of plots to assess the growth of tree species was established by the Research Unit of Parks and Gardens in the late 1960's. The plots included three provenances of *E.viminalis*. As regard the most successful provenance in terms of survival it was again a forest provenance (i.e. 100% as compared to 18% and 33%).

The third plot examined is about 100m to the west of the plot described above, and was established in 1969 by Dr. K. Eldridge. The experiment was to evaluate the survival and growth of 36 seed provenances of *E.viminalis*

FIG.5.2: *E.viminalis* of two seed provenances planted near Lake Ginninderra, Canberra. The trees in the background are of a forest provenance and the tree in the foreground is of a woodland provenance.

As many of the provenance replicates had died prior to 1982 the assessment was done on a qualitative basis. Most of the trees had done badly and so only those trees that had been 'successful' were recorded. The criteria used to record a tree as successful were: a substantial amount of recent new growth; a height of over 4m, and the presence of some adult foliage. There were originally 650 trees planted and of these 15 were recorded as successful. The others had either died or were stunted and badly damaged by insects.

All of the trees that were recorded as successful were from provenances over 700m in altitude and receiving more than 750mm annual rainfall.

Four of the seed lots trialled in the experiment were from provenances of lower rainfall than Canberra, but none were recorded as being successful in the above assessment. The seed provenance used for the experimental plantation in this study, namely, Lake George, was also included in the 36 provenances used in Belconnen. In 1975 it ranked 21st in height (Matheson, 1982 unpubl. data), and did not appear as a successful provenance in the 1982 assessment.

From all of the information that has been collected concerning the survival and growth of *E.viminalis* from different seed provenances, the forest provenances are the most successful in both experimental and landscape plantings. The most likely explanation for the greater success of the forest provenances is related to both insect attack and growth rate. Assuming that the growth rate is greater in the trees of mountain forest provenances, they are more capable of outgrowing insect damage. Also, it is possible that a woodland population such as the Lake George *E.viminalis*, when placed under increasing environmental pressure (in this case the reduced rainfall), may become weaker than the original forest population in relation to surviving even harsher conditions.

CONCLUSION:

The natural distribution of *Eucalyptus melliodora* indicates that it is a species adapted to such conditions as those in Canberra.

While the species grows well in Canberra it is not a cold climate tree, being usually restricted to altitudes below 600m. During winter in this study all of the naked buds on *E.melliodora* were excised and thus avoided the cold conditions. This avoidance was further aided by what appeared to be a photoperiodic response in late autumn.

When growth recommenced in the early spring it did not result in a rapid increase in height, but rather the number of growing points on each new shoot increased rapidly and emphasised the trees' decurrent form. To provide support for the spreading crown the relative stem diameter growth was greater than for the height. The rate of height growth increased until November when it was at its greatest and then declined until

February. The growth, however, did not stop even during January with the trees continuing to transpire and photosynthesize during the hottest periods, possibly with the assistance of osmoregulation.

As a plantation tree in Canberra *E.melliodora* has been successful mainly due to its natural adaptation to the local climate, its apparent resistance to a large number of destructive insect pests and its effective regeneration from lignotubers. However, the species was still shown to benefit from a period of establishment. Also, due to the susceptibility of its young shoots to desiccation caused by wind in early spring, it is better planted on the leeward side of a plantation provided light is not limiting.

Eucalyptus viminalis was found to differ in many ways from the locally occurring *E.melliodora*.

The *E.viminalis* (Lake George provenance) used for this study, despite being previously described as a woodland tree, had a definite forest (i.e. excurrent) growth form. Unlike the *E.melliodora* there were fewer growing tips on each shoot and most of the trees retained a dominant leader. The *E.viminalis* was much faster growing, in both height and stem diameter, and matured earlier both vegetatively and ontogenetically.

The species' greater ability to tolerate cold conditions was illustrated by its continued growth during winter. This was mainly the result of the buds not becoming desiccated. It did not show any photoperiodic response and its height growth was controlled by temperature. Growth stopped when the mean temperature fell below 10°C.

As with *E.melliodora, E.viminalis'* height growth rate increased from September until November when it was at its greatest, and the day/night temperature regime was 24°/10°C. In the first year there was also rapid growth in December but this did not occur in the second year. This was possibly due to a decrease in the optimum growing temperature over the two years.

The reduction in growth rate during the summer period was greater for *E.viminalis* than for *E.melliodora*. During these periods of high temperature and associated water stress (particularly for the unirrigated trees) *E.viminalis* closed its stomata, which reduced water loss but also reduced CO_2 uptake, photosynthesis and growth.

The failure of *E.viminalis* in plantations in the Canberra environment has been mainly the result of the species' susceptibility to insect attack and its response to water stress as emphasised by poor growth with lack of establishment.

Because of this the use of insecticides, particularly in November when the most damage is done, is advantageous.

Although insect damage is most likely the cause of the trees' eventual death, an earlier decline in the trees' growth rate is likely to be a major contributor to it.

So as to enable early rapid growth, the "establishment period" is more important than any irrigation or spraying for insects after those first three months. Also, as the growth of the "unestablished" trees was reduced in November, probably as a result of water stress, the effect of the insect damage was magnified.

Once established, *E.viminalis* will, for the first two years at least, grow rapidly whether irrigated or not. If *E.viminalis* is irrigated, it should be in October-November and March-April when the trees are growing at their fastest. In the first year's growth, irrigation in December and February may also be beneficial.

Being a fast growing species that is not affected by wind desiccation in winter it is suitable for use as a wind-break for other species such as *E.melliodora*.

Assuming that *E.viminalis* from mountain forest provenances are capable of more rapid growth (and possibly establishment) and also have more pronounced apical dominance, then the reason for their greater success than the Lake George *E.viminalis* becomes more evident.

Despite the marked success of those *E.viminalis* grown in the experimental plantation at the Cotter Plots, it still should not be a species considered for widespread planting in Canberra mainly because of its susceptibility to such a wide range of insect pests. However, its use in irrigated areas receiving regular maintenance is still highly desirable, particularly if the seed used is of a mountain provenance.

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